



The DRIFT Directional Dark Matter Search

Dinesh Loomba

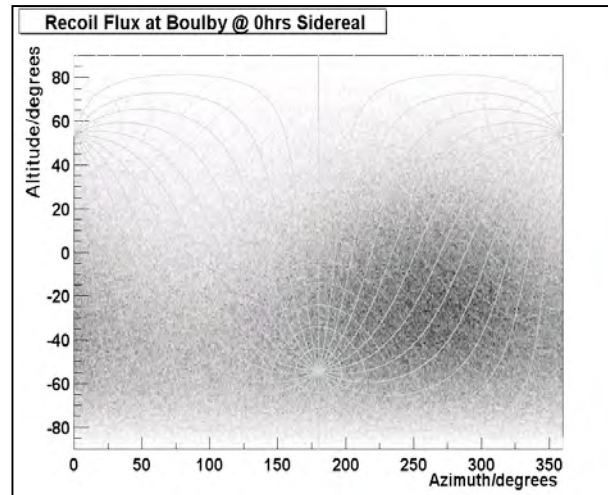
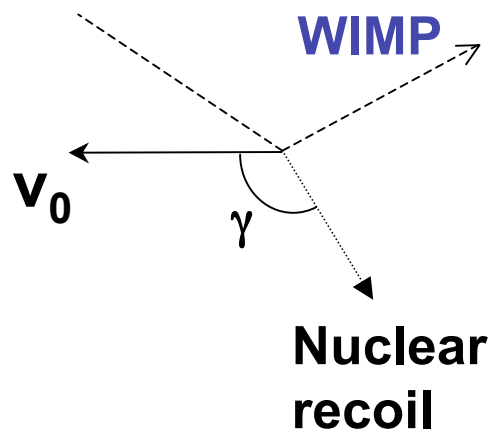
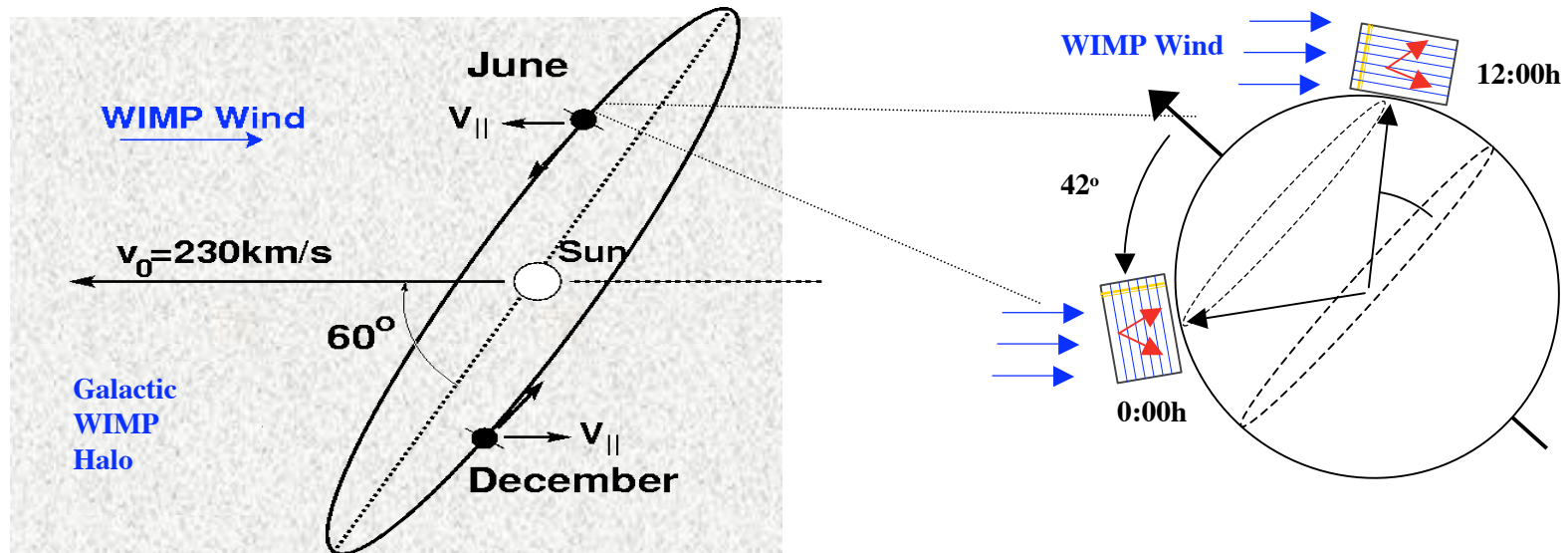
For the DRIFT Collaboration

INFO 13, Santa Fe

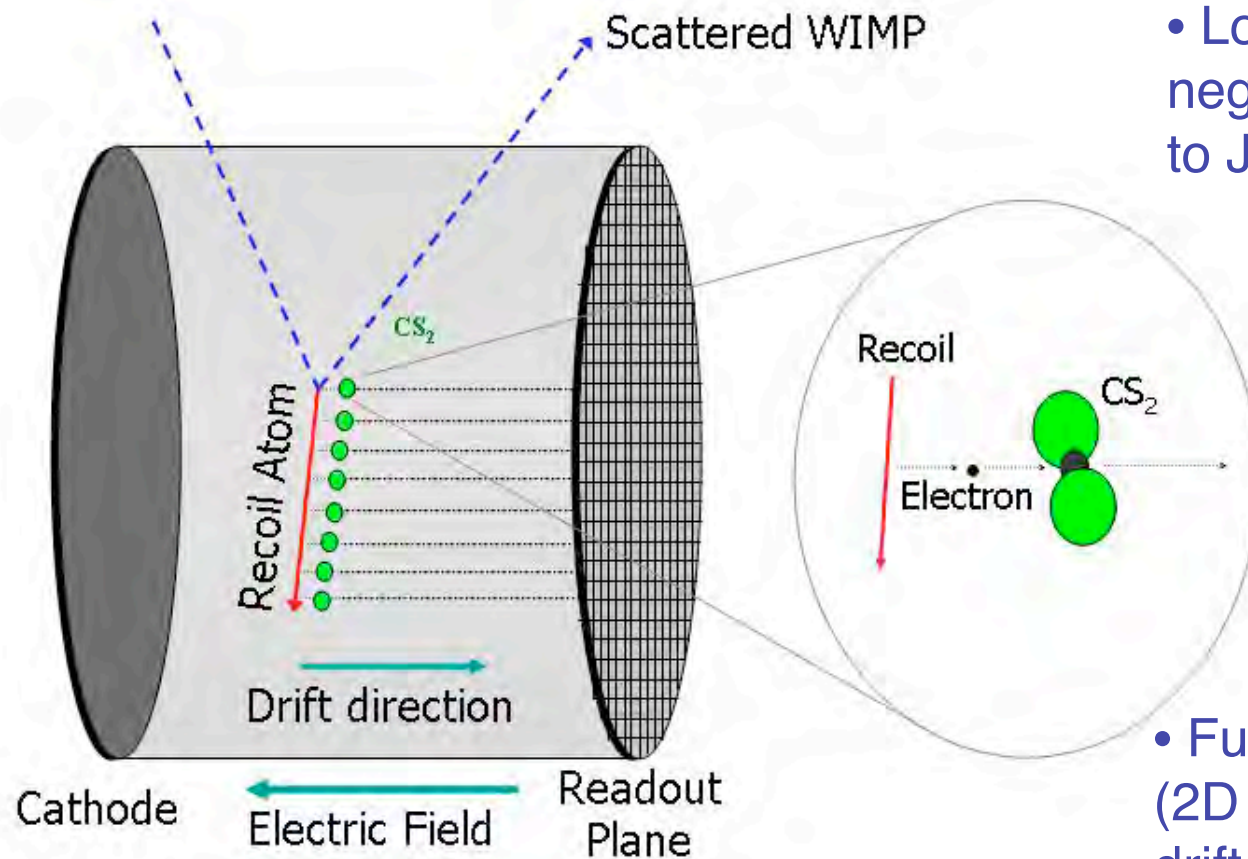
August 27 2013



The WIMP directionality signature



The DRIFT detector - a direction-sensitive low pressure NITPC

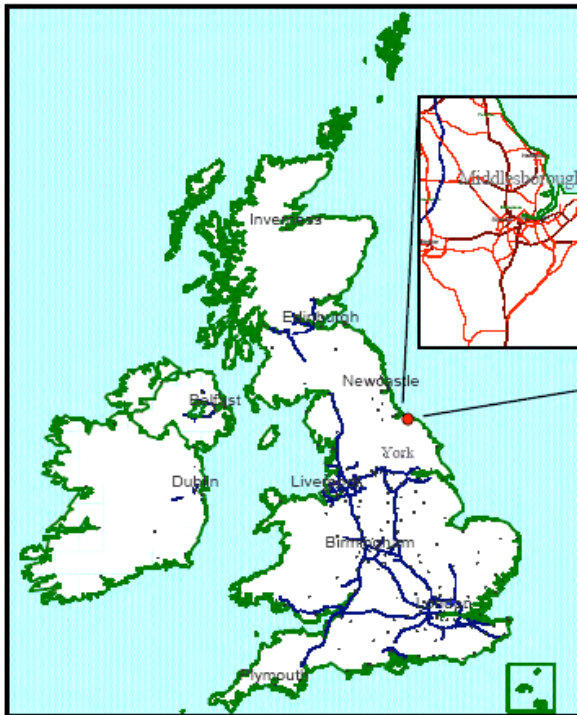


- Low diffusion using negative ion drift (idea due to Jeff Martoff).

- Full 3D track reconstruction (2D readout + timing along drift direction) possible
- Low pressures (40 Torr) required to extend range of nuclear recoils to a few mm

DRIFT is located in the Boulby Mine in UK

- Working Potash mine
- Deepest mine in Britain
- 850m to 1.3km deep



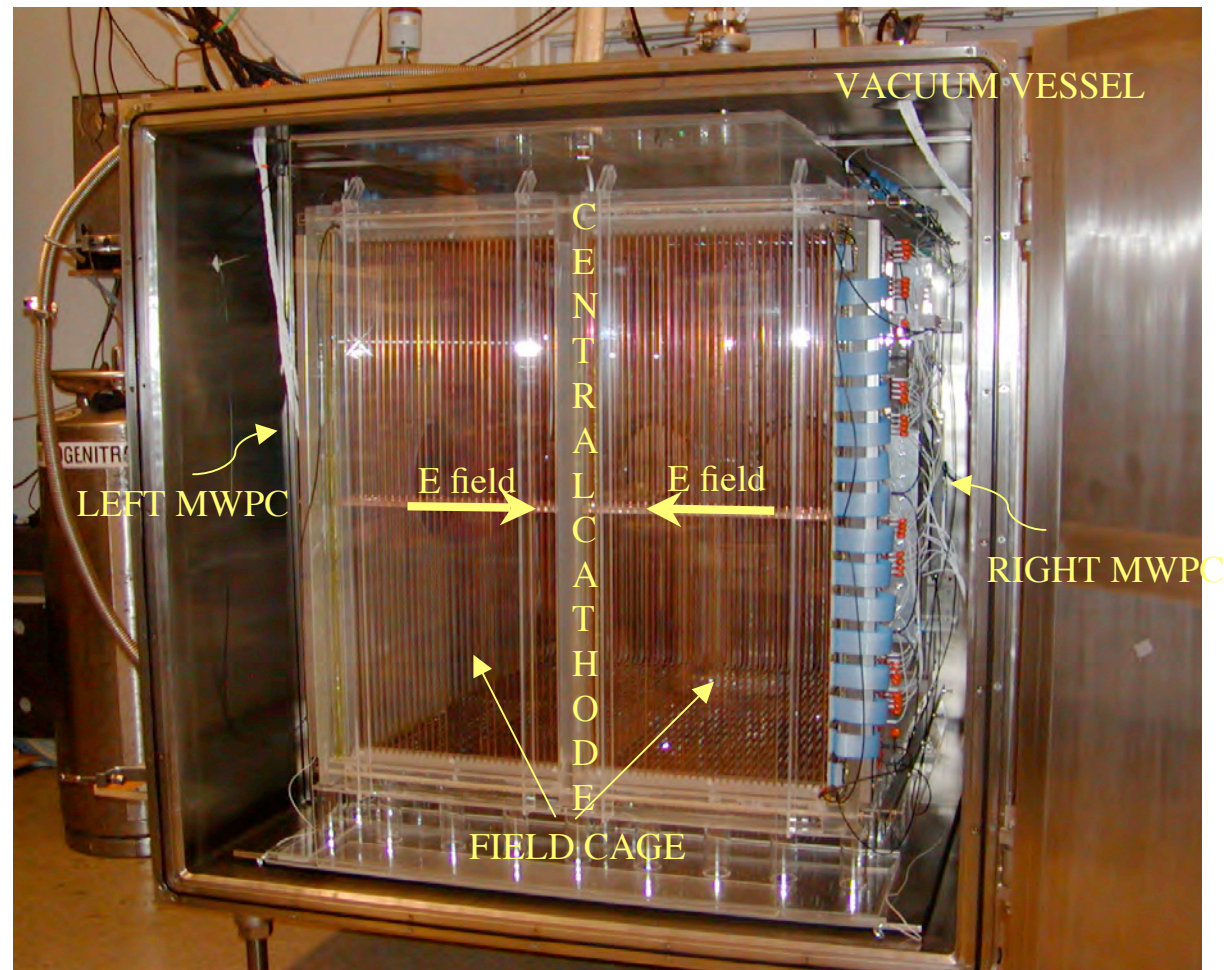
Sylvanite



The DRIFT-II detector in the Boulby Mine

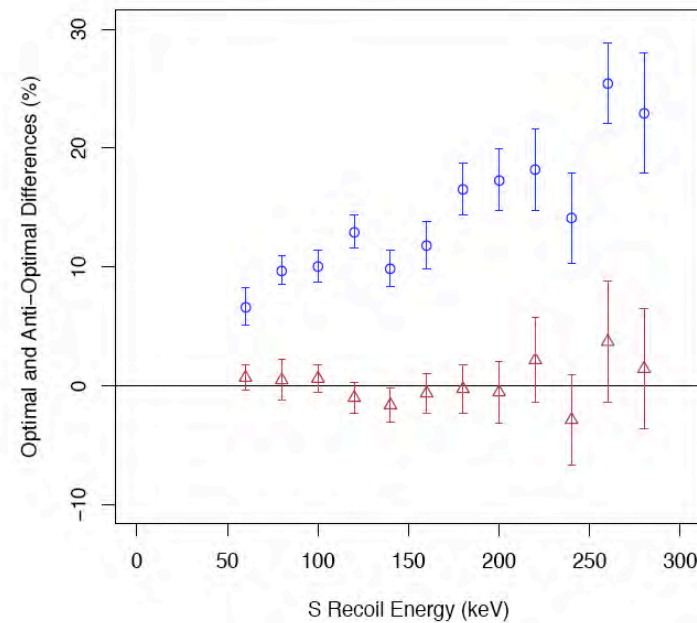
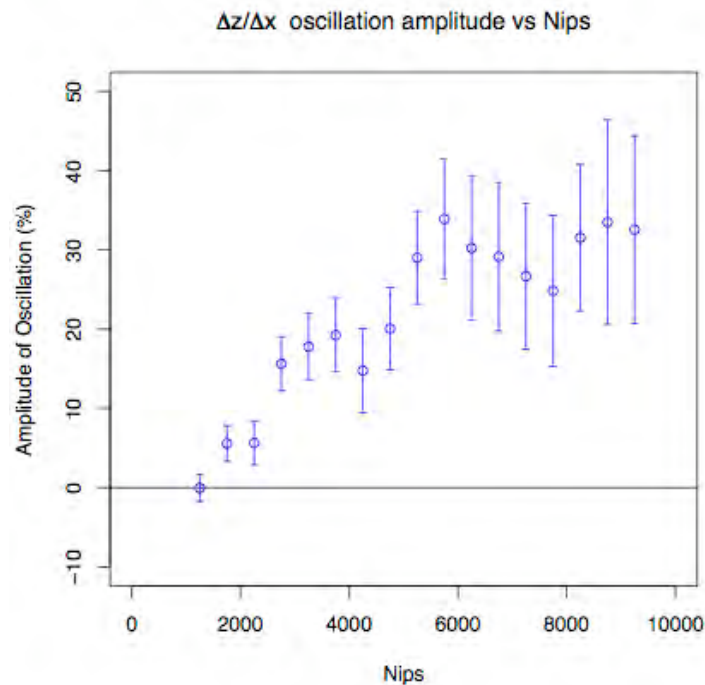
The detector volume is divided by the central cathode, each half has its own multi-wire proportional chamber (MWPC) readout.

0.8 m³ fiducial volume, 10/30 Torr CF₄/CS₂ --> 139 g



Directional sensitivity of DRIFT

- DRIFT has 2, independent, directional signatures (range components and head-tail sense of recoils).
- Combining these two directional signatures enables DRIFT to detect WIMPs with few 10's of events at the 90% C.L.

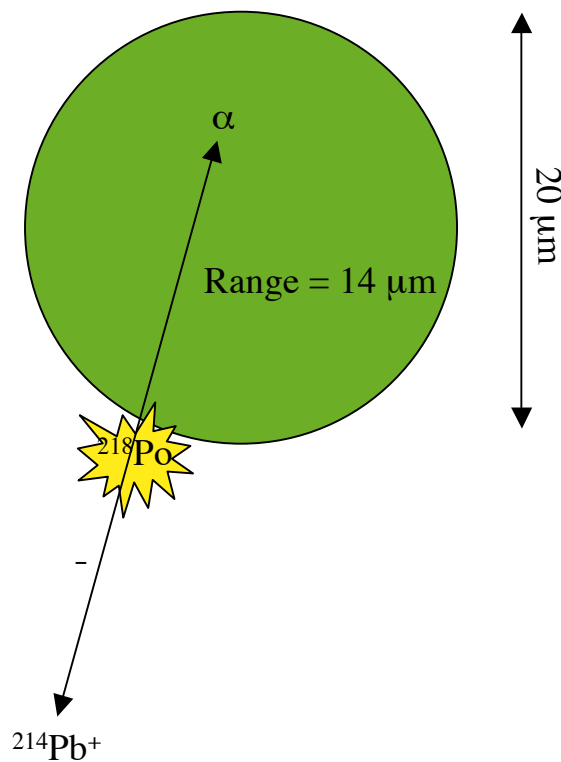
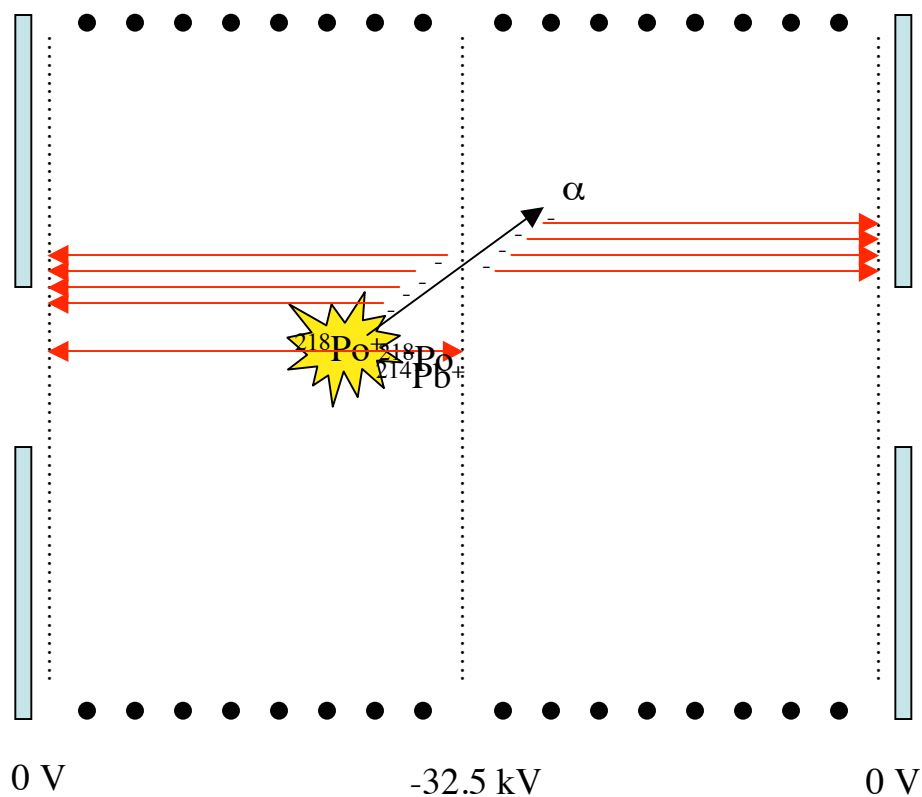


S. Burgos et al., Astropart. Phys. 31 (2009) 261-266

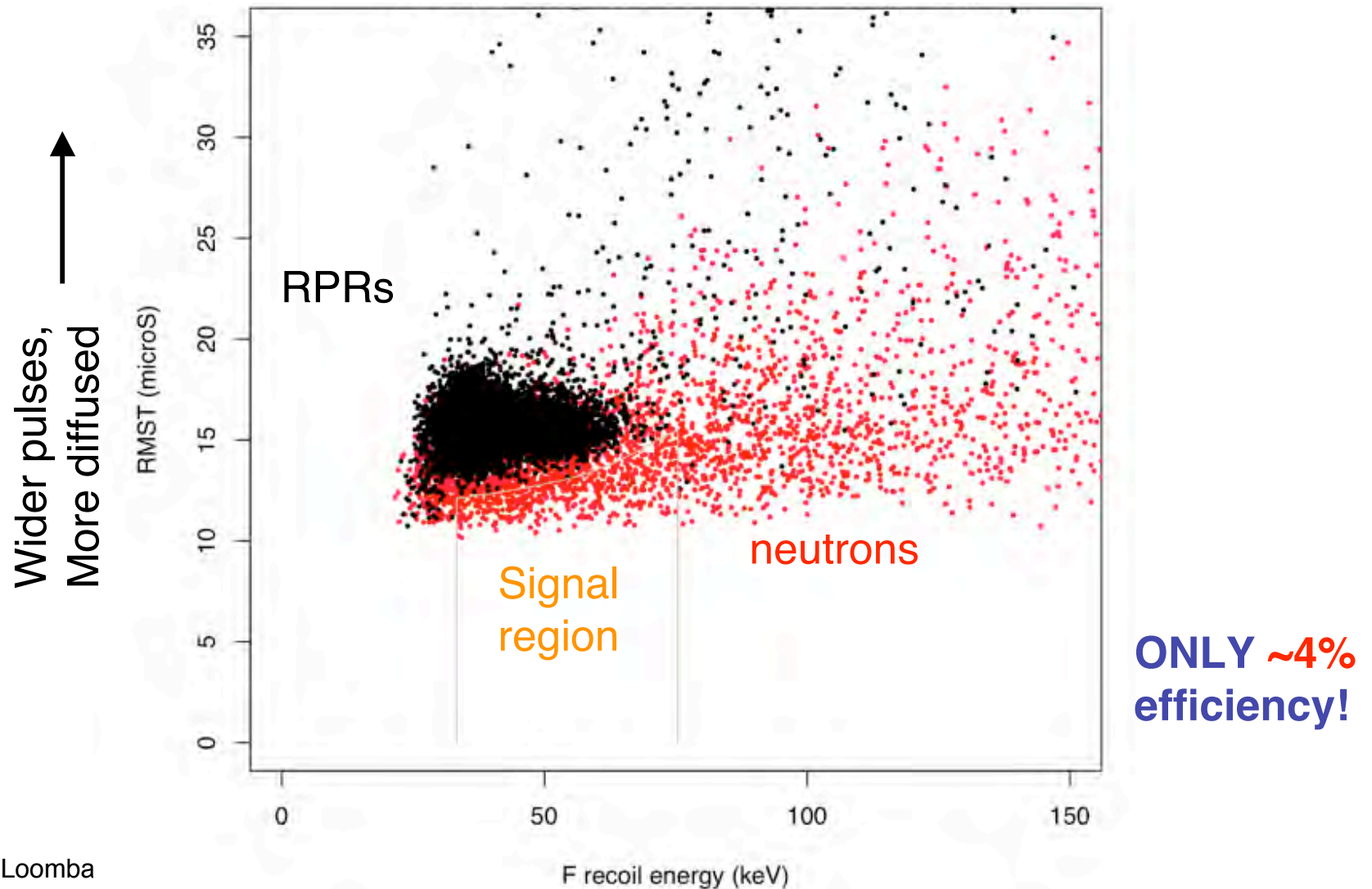
S. Burgos et al., NIM A600 (2009) 417-423

Recent progress and results

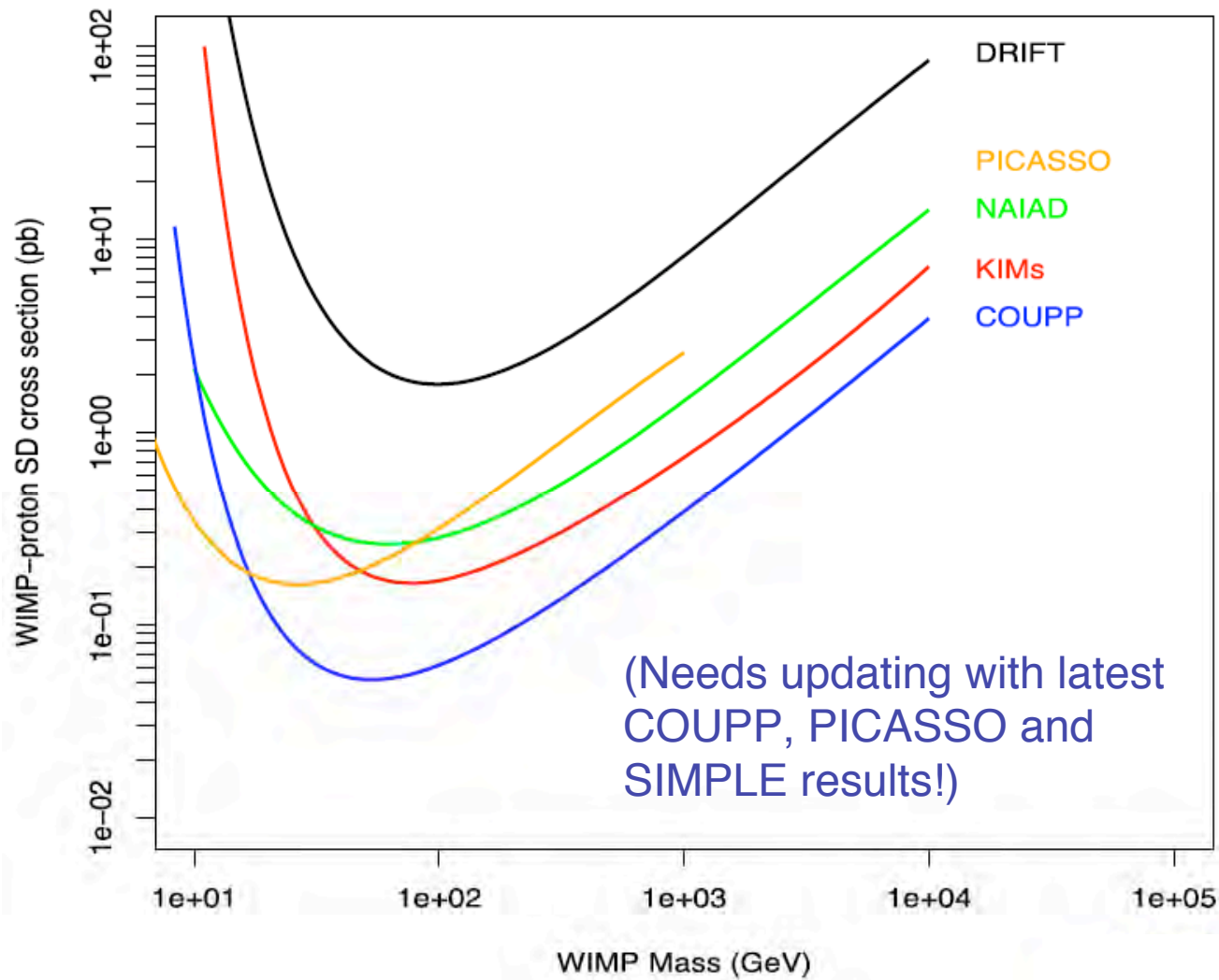
DRIFT's backgrounds are dominated by Radon Progeny Recoils (RPRs):



RPRs have large pulse-widths as expected from **maximally diffused** tracks drifting from cathode. **So, RPRs may be removed in analysis** (Data from 2009/2010 shielded WIMP runs 47.2 days, **130 \pm 2 events per day!!**):

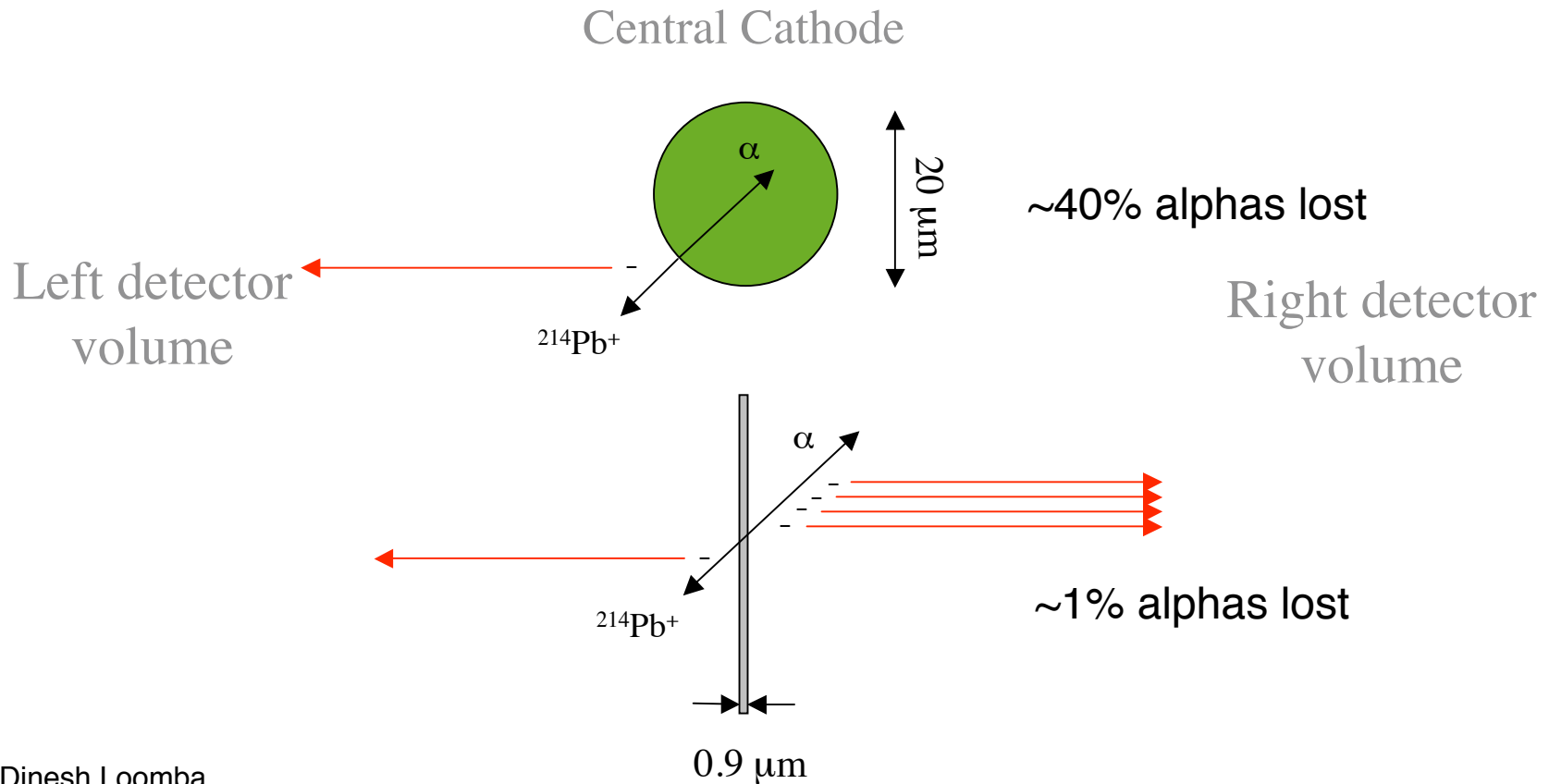


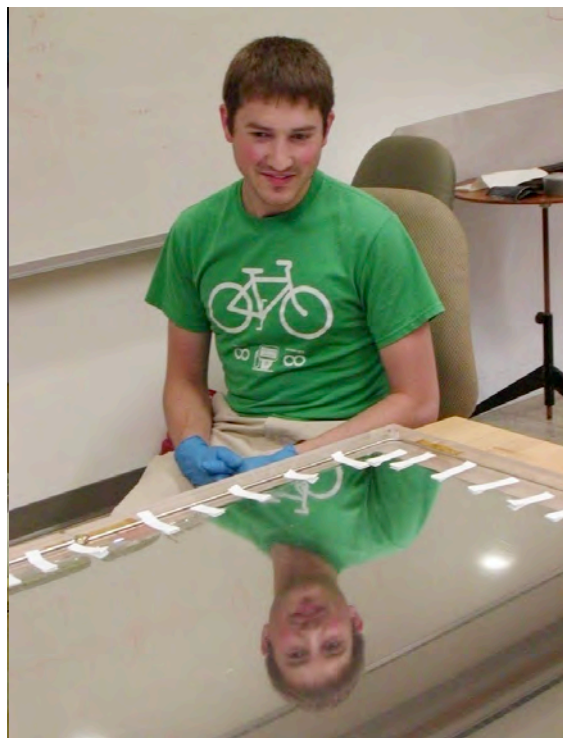
SD WIMP-proton limit with 30-10 CS₂+CF₄ and a 47.2 day exposure



Progress on reducing RPR background

A cathode transparent to α 's from RPRs will provide a tag to **veto** these events:





Multi-panel **$0.9\mu\text{m}$** thick
DRIFT cathode constructed
underground at Boulby and
installed in DRIFT-IIId

With the 0.9 micron thick cathode the projected RPR rate was expected to drop from 130/day, from wire cathode, to $\sim 3/\text{day}$.

The R&D over the past few years has yielded:

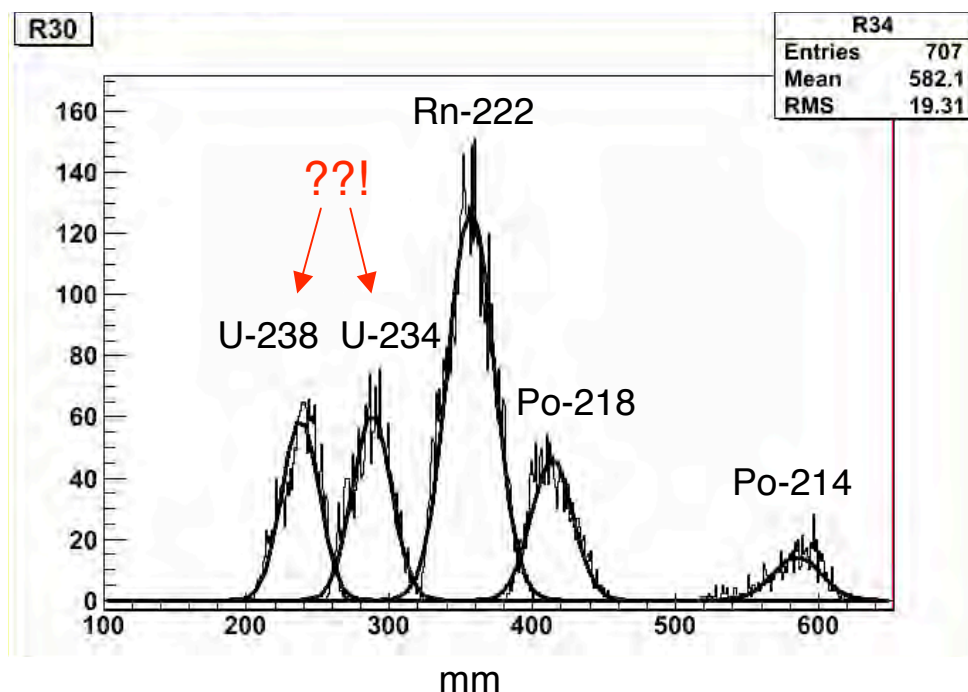
- 1st version reduced the rate to $\sim 7/\text{day}$...
- 2nd version reduced it to $\sim 2/\text{day}$...
- Final version, reduced it to 0.5/day, a factor 260 reduction

The improvement in RPR veto efficiency was made using novel hardware and analysis techniques (Eric Lee and Eric Miller at UNM).

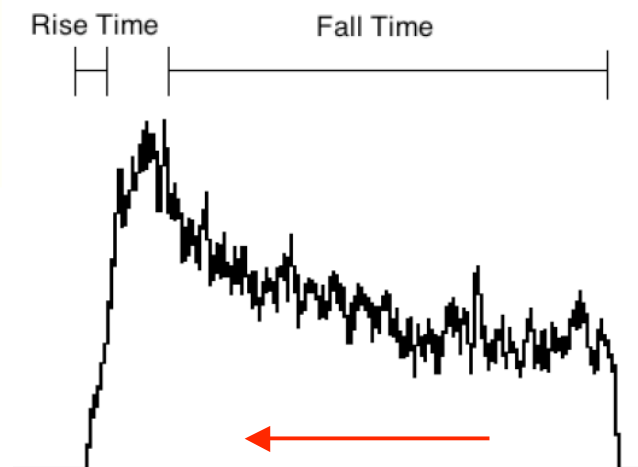
This story is interesting and worth telling ...

Analysis: Using Alpha Spectroscopy to make in situ measurement of contaminants

The 3D range of all fully contained alphas in DRIFT:

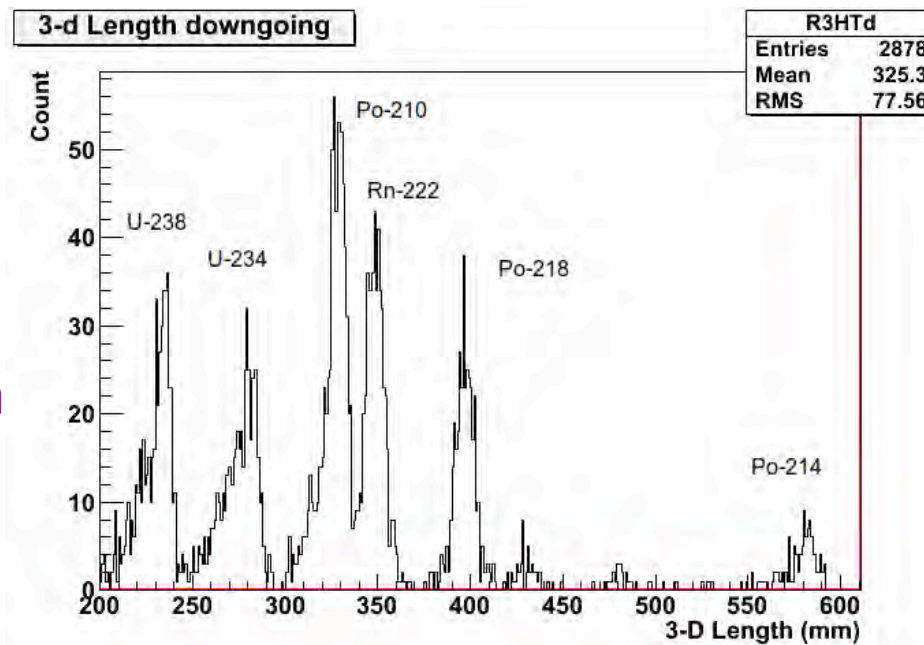


Using the Bragg curve we can determine alpha direction, which we use to...

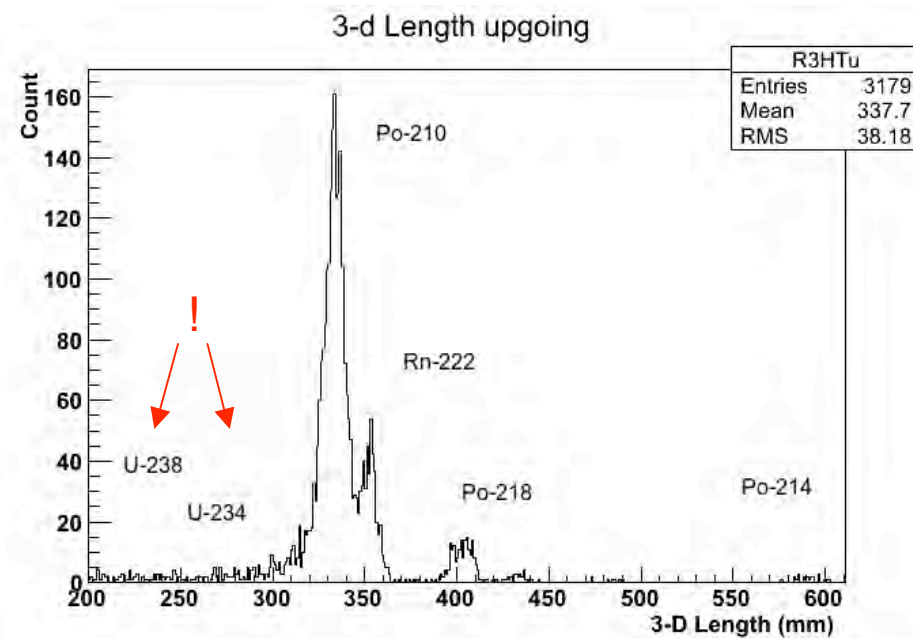


...say that all of the U is in the thin film!

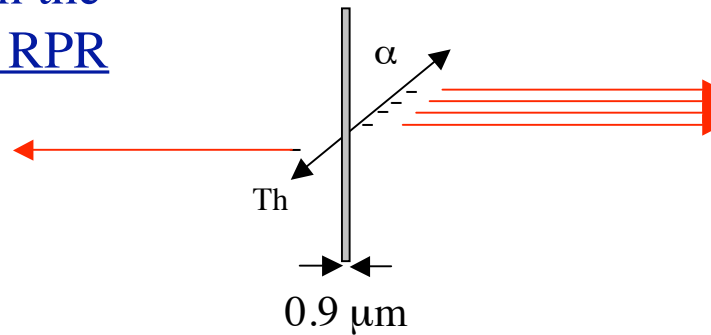
Alphas directed away from cathode):



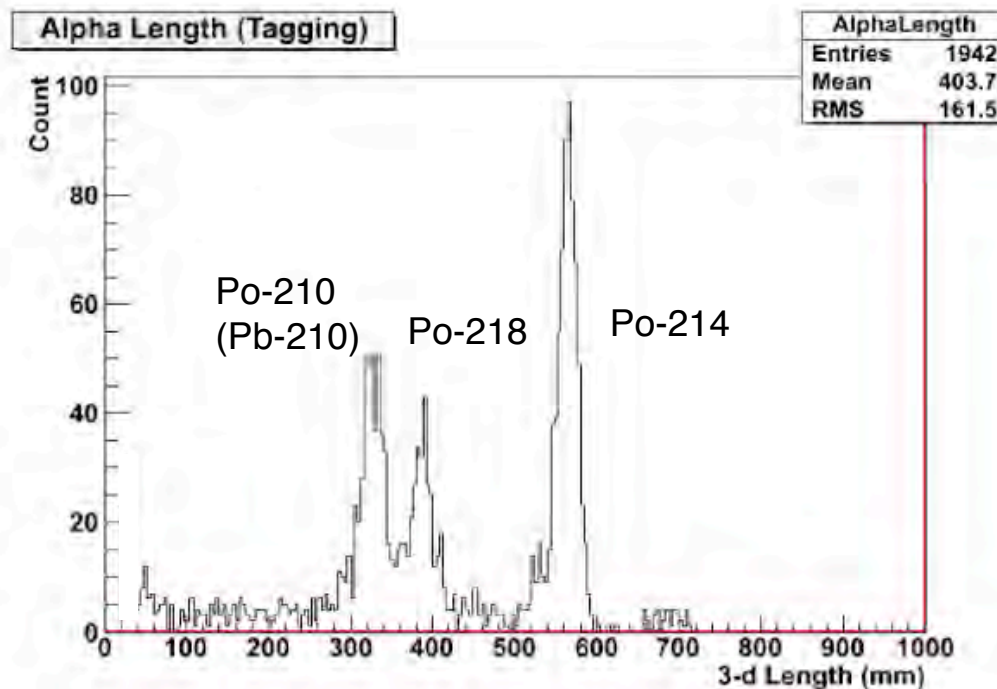
Alphas directed towards the cathode:



To see where the U lies in the thin film, look at Tagged RPR alphas:



The range of tagged RPR alphas:



...No Uranium!

Its NOT on the surface, but inside the aluminum where the recoils can't come out.

The Pb and Po are mostly on the surface.

Summary of backgrounds from central cathode

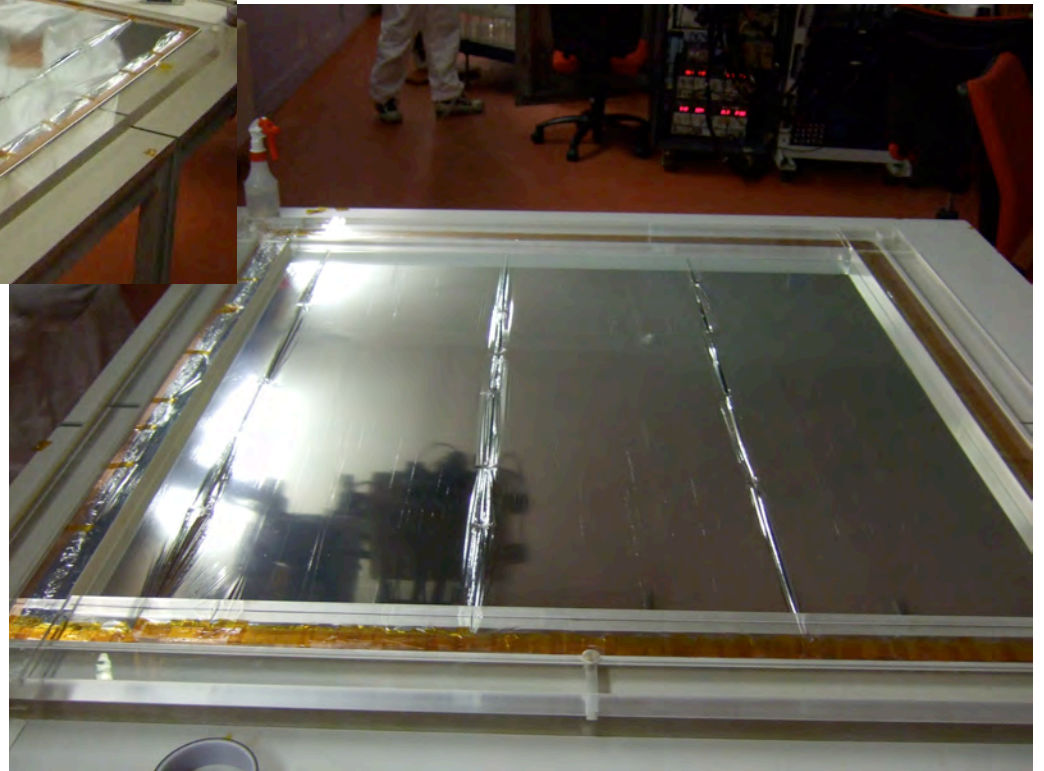
- Uranium isotopes inside film --> untagged lower energy alphas that can sometime mimic RPRs
- Pb-210 at surface of thin film --> RPRs
- Rn-222 in gas --> radon progeny that can plate out on cathode
- Polonium isotopes (Radon progeny) mostly plated out on surface of thin film --> RPRs

This was the 1st iteration. For the 2nd iteration we made the cathode out of Radiopure Aluminum.



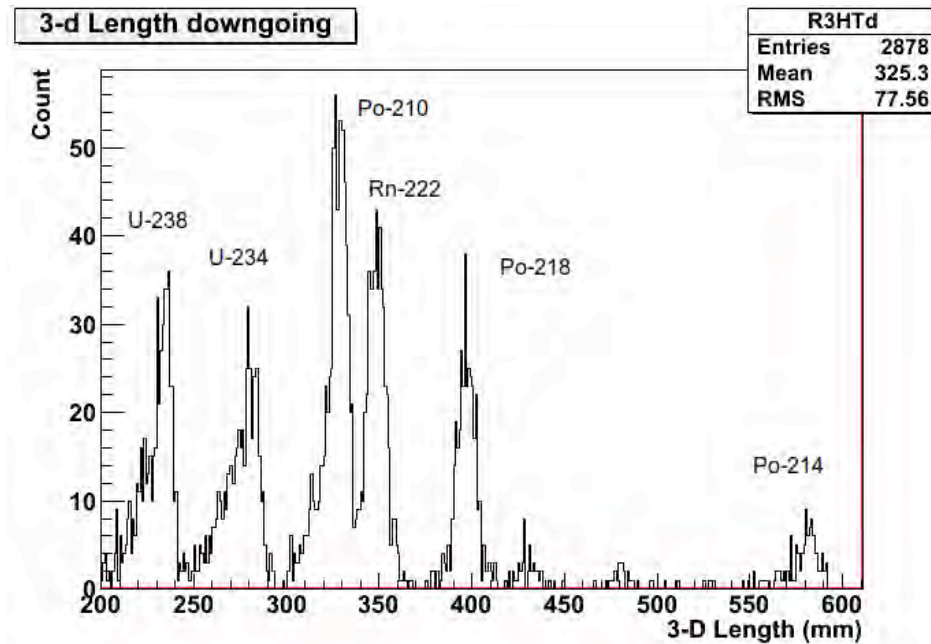
2nd Iteration: Radiopure flat cathode installed in DRIFT-IIId in June 2012 and data taking has started.

Preliminary analysis of unshielded data indicates that the background events from cathode are down to $\sim 2/\text{day}$ (lower by $\times 60$ from wire cathode)

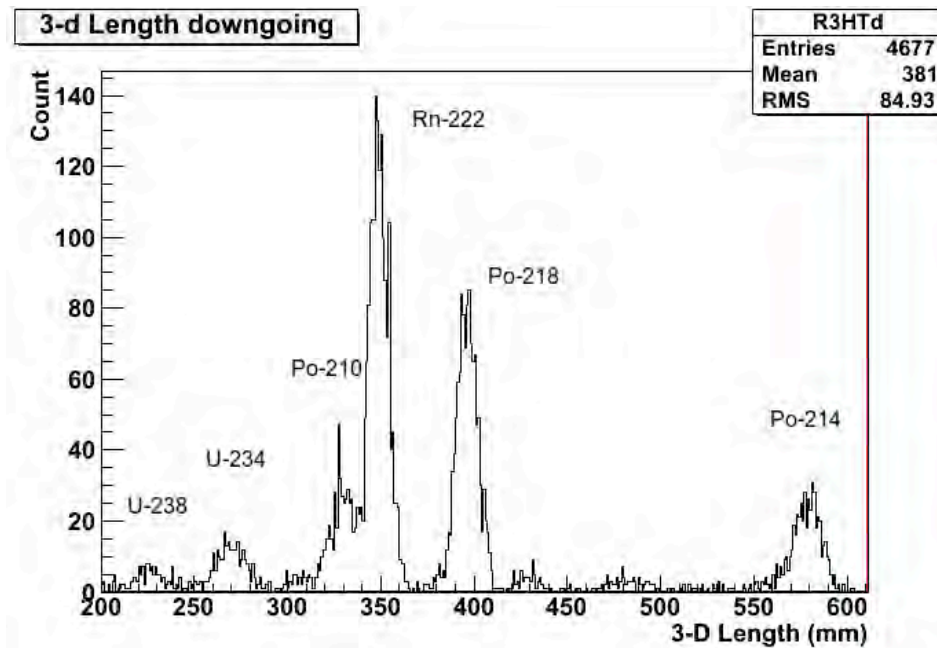


INFO 13

Dirty: (~15 days)



Clean (~50 days):



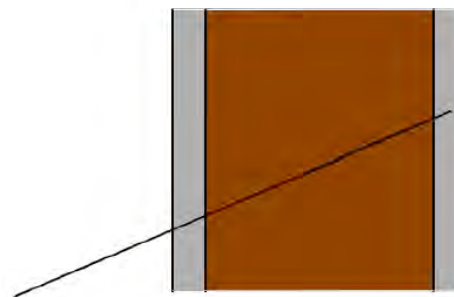
In summary, after correcting for efficiencies we obtain the following contamination numbers:

| Isotope | Dirty | Clean |
|------------------|------------------------|--------------------------|
| ^{234}U | $14 \pm 1.2\text{ppt}$ | $2.5 \pm 0.24\text{ppt}$ |
| ^{238}U | $284 \pm 22\text{ppb}$ | $20 \pm 2.4\text{ppb}$ |

DRIFT has amazing sensitivity to backgrounds measured in-situ from detector materials!

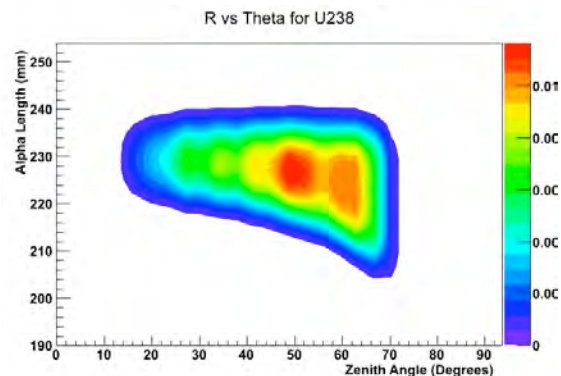
It gets even better...
We can pinpoint location of U:

Al Mylar Al

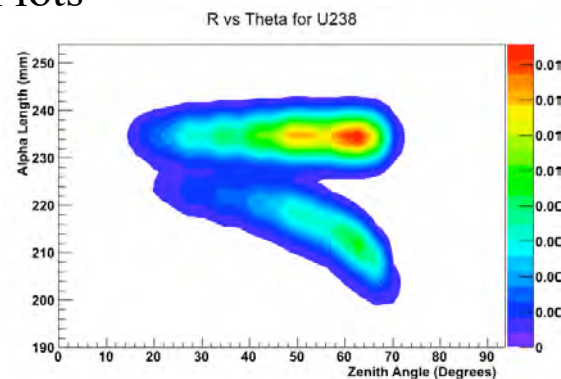


R vs. Theta Plots

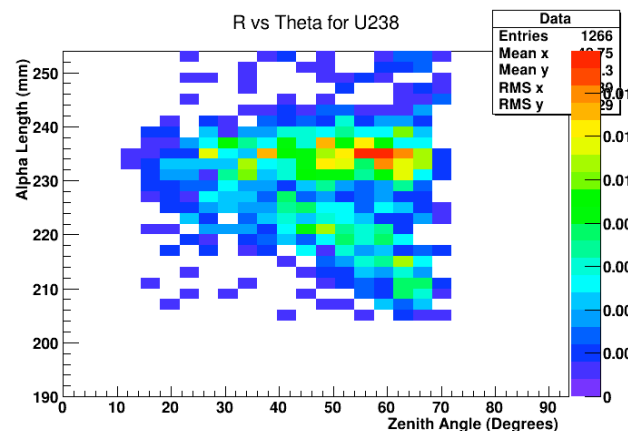
Mylar only



Al only



The data



(Analysis by Eric Miller,
UNM PhD student)

The Erics



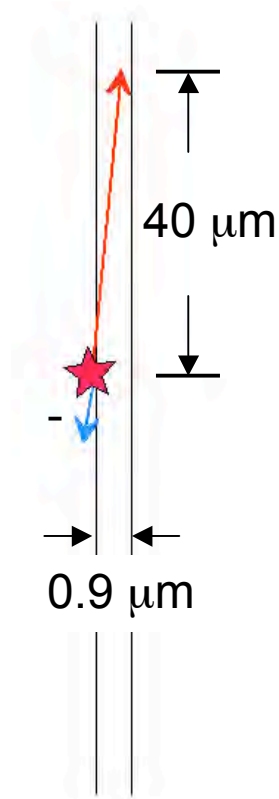
Dinesh Loomba



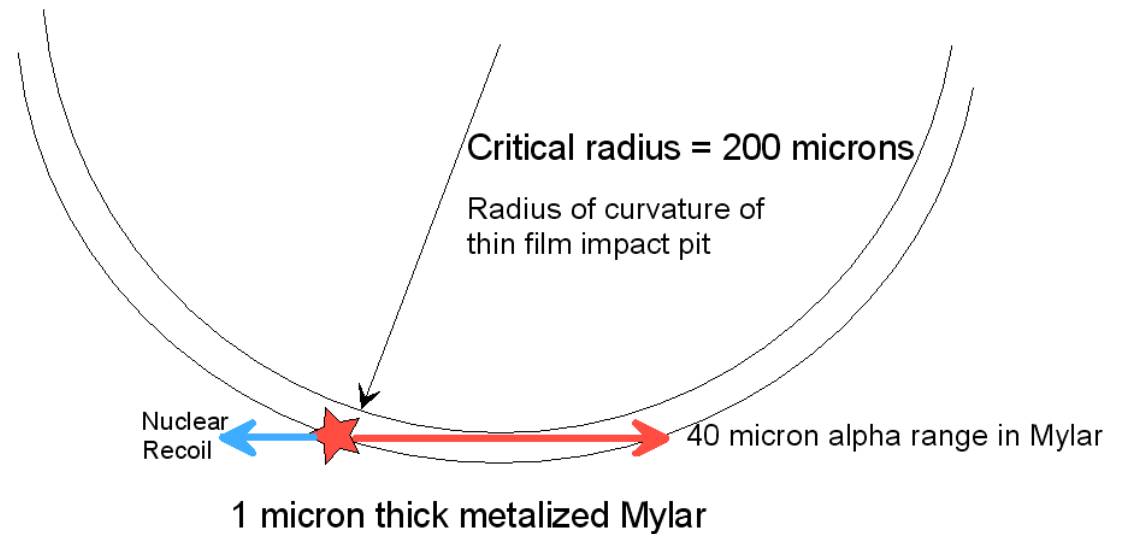
INFO 13

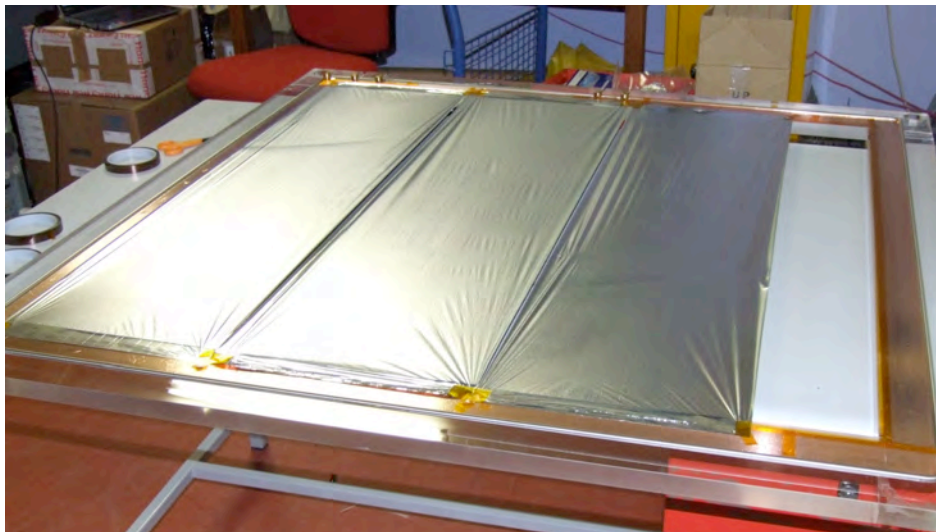
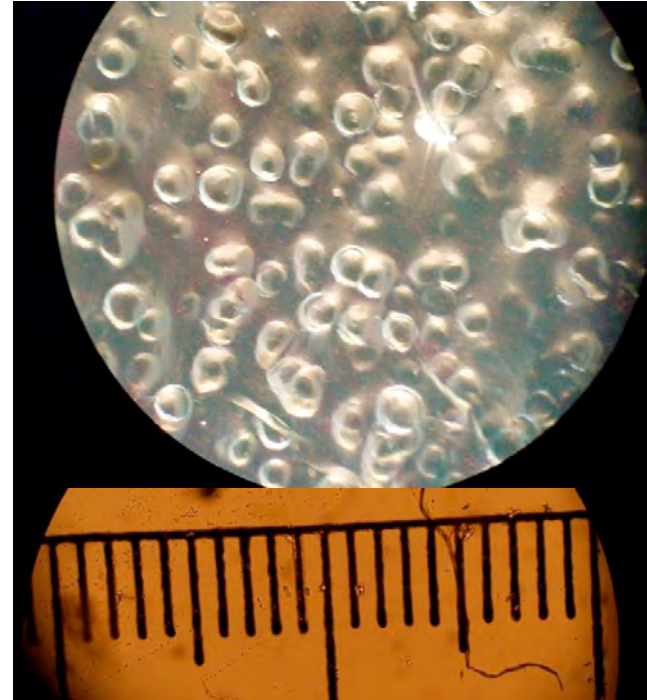
3rd Iteration: Micro-textured Thin Film

The problem: thin film cathode reduces but does not eliminate untagged RPRs



Possible solution: texturize the thin film with hemispherical features with scale size ~ 100 microns





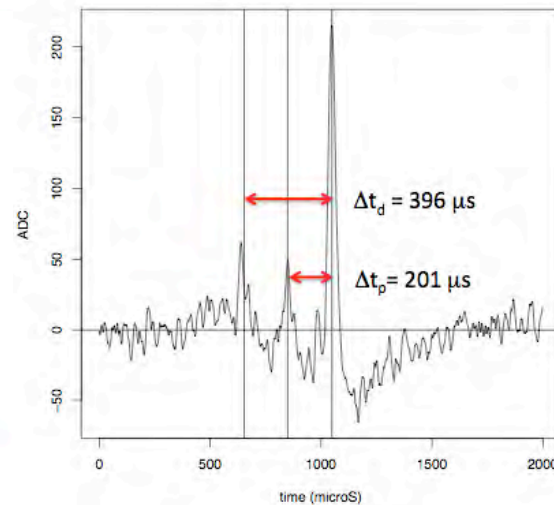
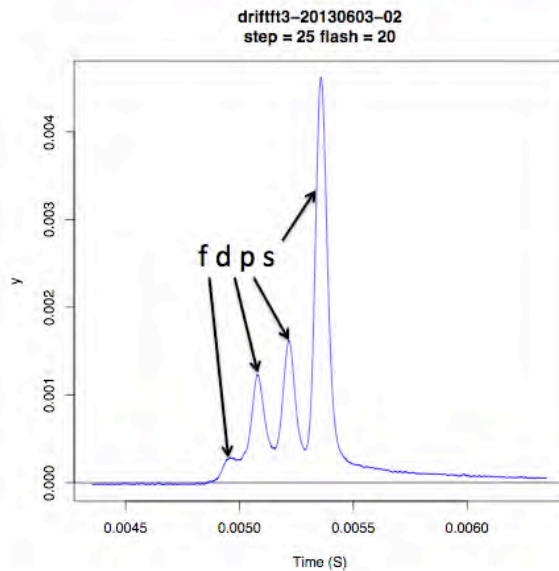
Final panels constructed and installed in DRIFT-IIId a ~few months ago: brought the RPR rate down to $\sim 0.5/\text{day}$

The “Holy Grail” of RPR elimination: Z-fiducialization

Recently, a serendipitous discovery by Dan Snowden-Ifft, has led to a method to fiducialize the detector along the drift (z) direction. This will enable us to locate and veto all of the remaining events coming from the cathode. The discovery is a game changer for DRIFT. **It has allowed our signal region efficiency to grow by as much as a factor 20-25 -> in ~2 days of running we equal our previous 50 day limit.**

30 Torr CS₂ + 10 Torr CF₄ + 1 Torr O₂

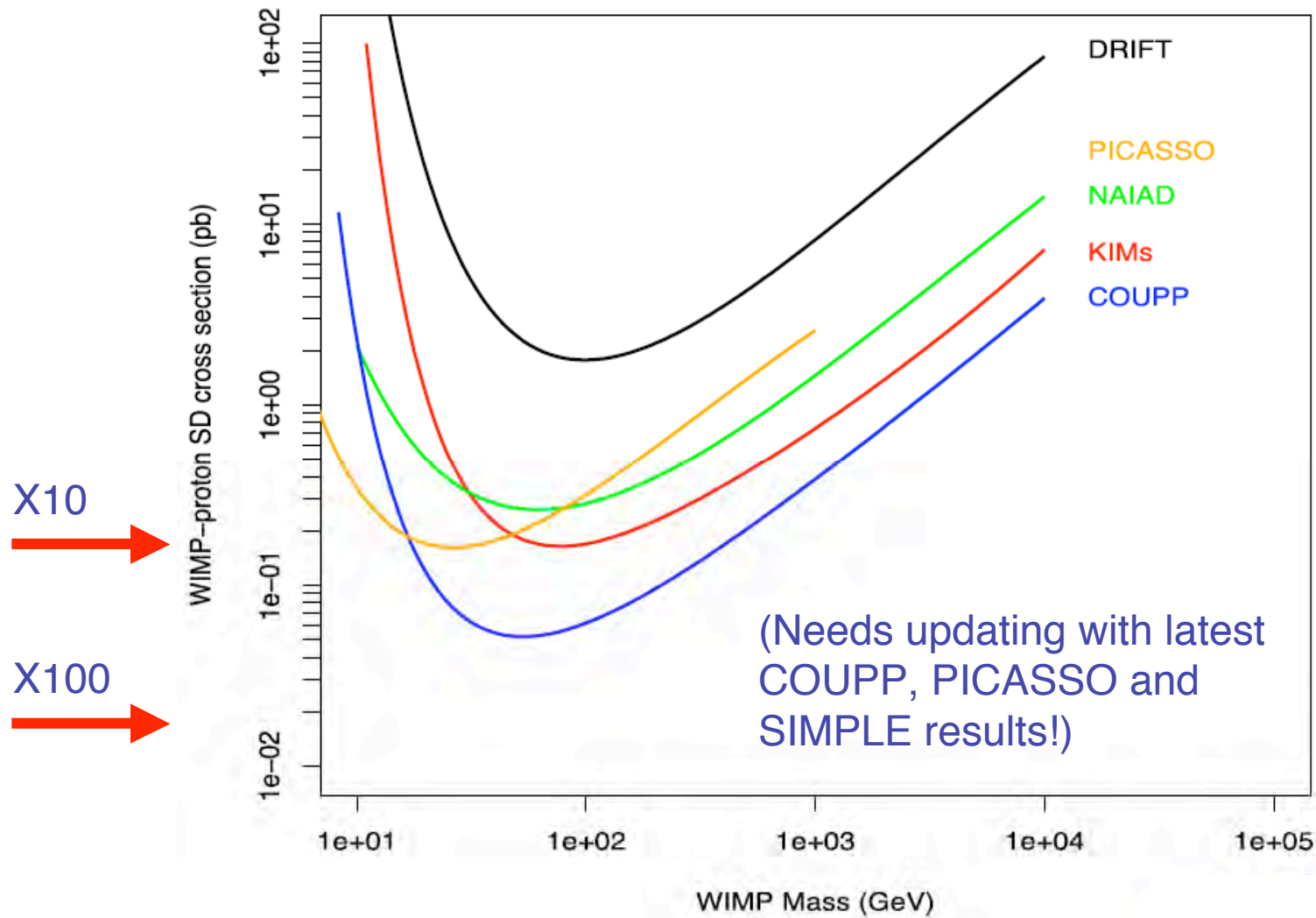
Tagged RPR Measurements



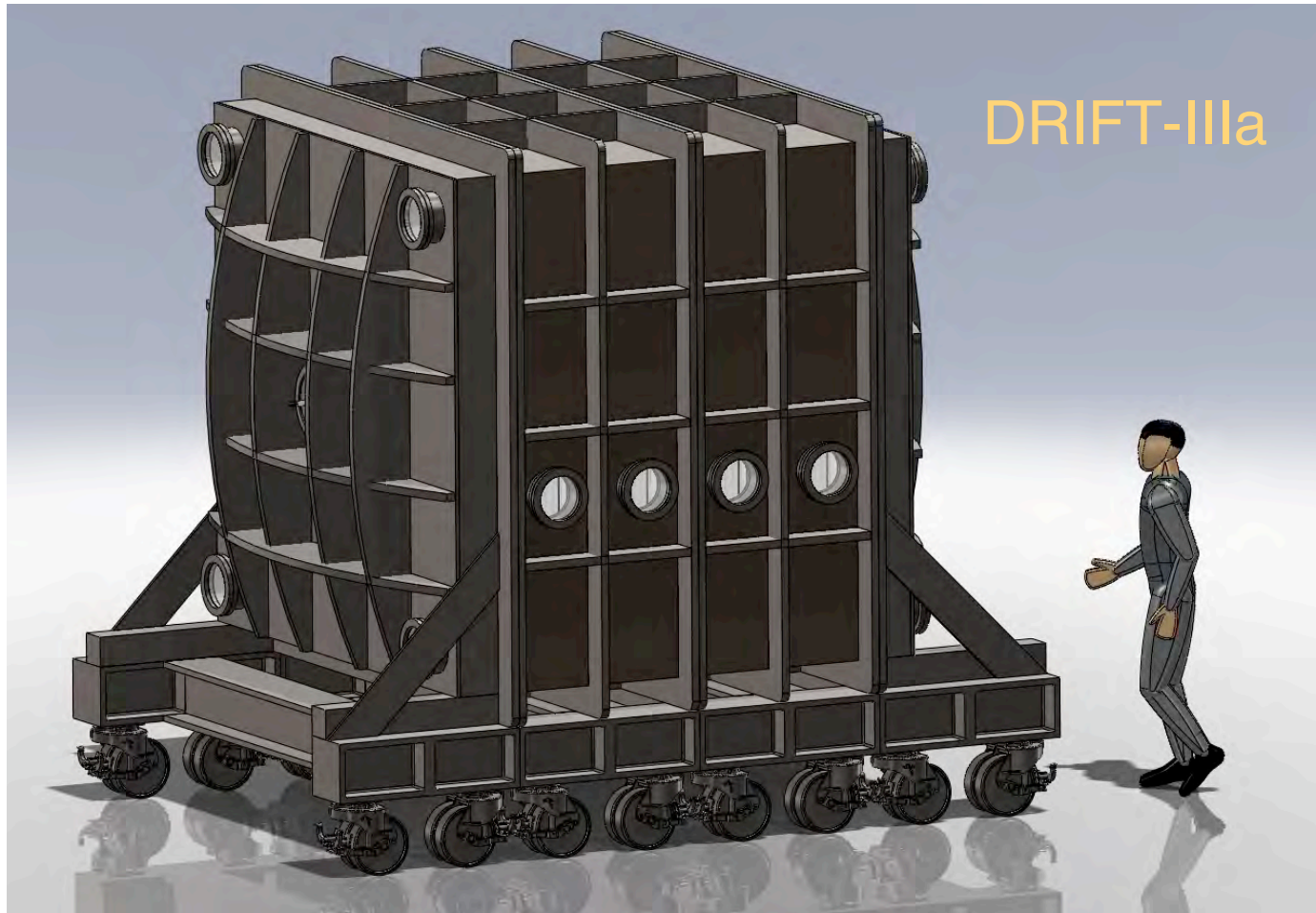
- This event from the central cathode has the predicted Δt_s to within a few %.
- This also shows that nuclear recoils possess the minority peak signature.
- Overshoot in the electronics poses an analysis challenge for us.
- $\frac{\Delta t_p}{\sigma_s} = 11.5$ @ 50 cm!

D. Snowden-Ifft, CYGNUS 2013, arXiv:1308.0354

SD WIMP-proton limit with 30-10 CS₂+CF₄ and a 47.2 day exposure

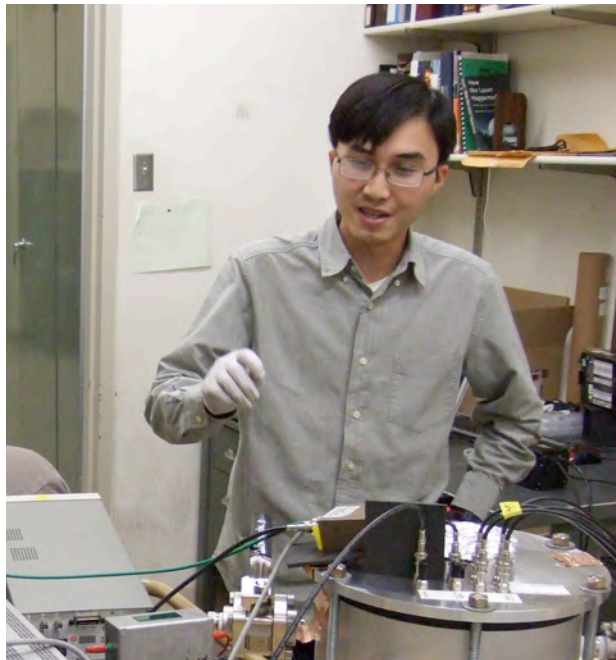


DRIFT has now entered a new phase, going from being background limited, to being volume limited. Ready to scale up to a 24m³ target volume DRIFT-III detector.

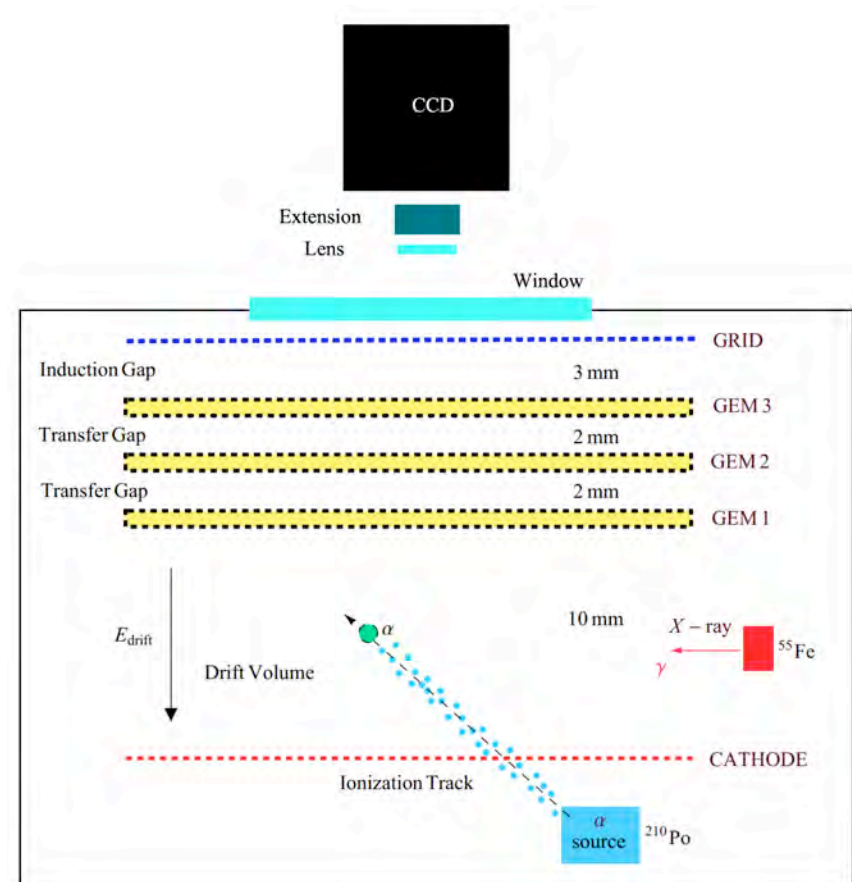


R&D towards a directional experiment for low-mass WIMPs

CCD-GEM based detector to study electronic and nuclear recoils with high signal-to-noise and high spatial resolution



Nguyen Phan (PhD student, UNM)

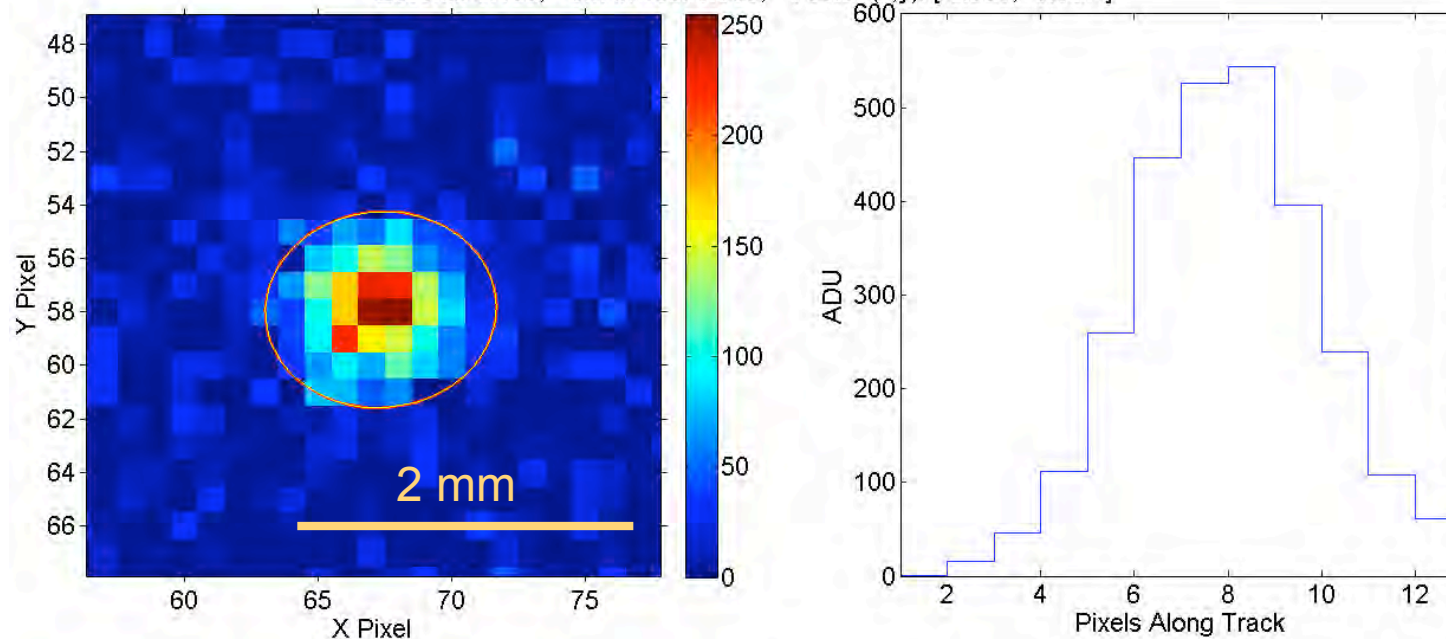


Experimental Parameters

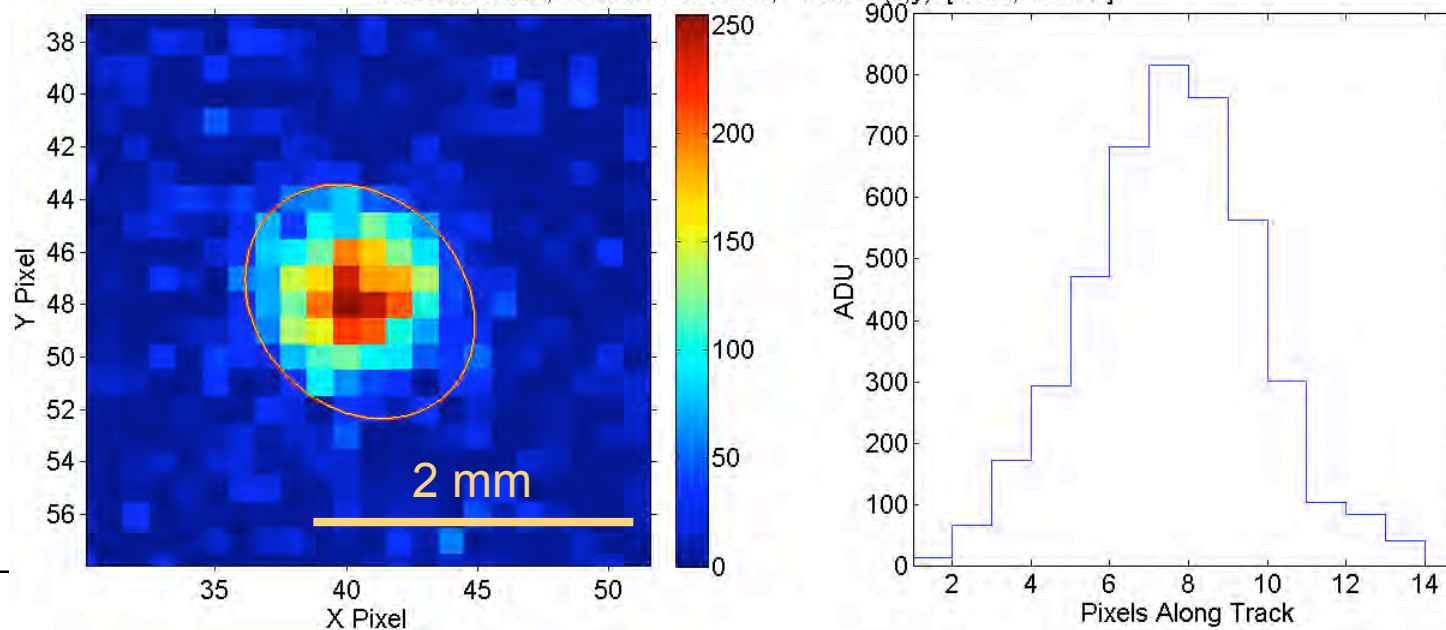
- 3 standard copper CERN GEMs (7 cm x 7 cm).
- Pressure: 100 Torr pure CF₄
- Effective gain: ~400,000
- Diffusion: $\sigma=350$ μm
- FLI back-illuminated CCD (peak QE ~ 93%, read-noise 10 e- rms)
- 6 x 6 on-chip binning, 5 sec. sequential exposures.
- Energy resolution: 35% (FWHM) at 5.9 keVee

Nuclear Recoils

Detected Energy: 10 keVee, Recoil Energy: 23 keV, Track Length: 1.3 mm
 Track Length: 7.622 pixels, Track Area: 85 pixels, Angle: -4
 Eccent.: 0.435, Skewness: 0.039, Vector (x,y): [0.998, -0.067]

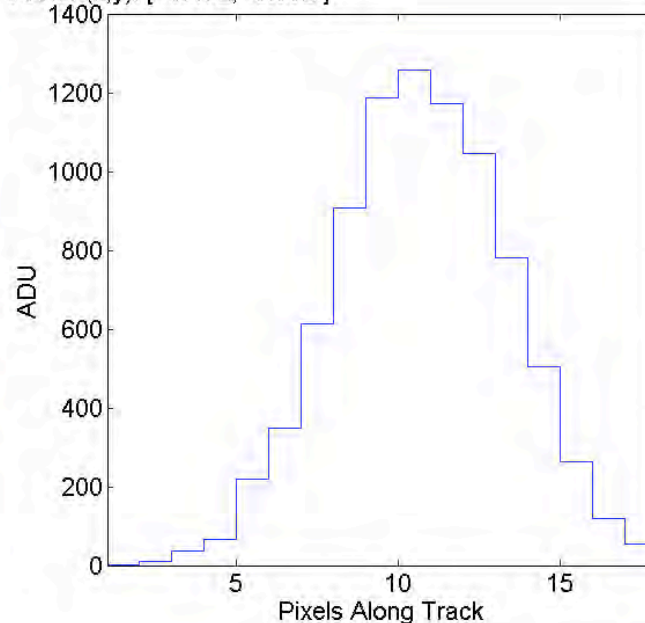
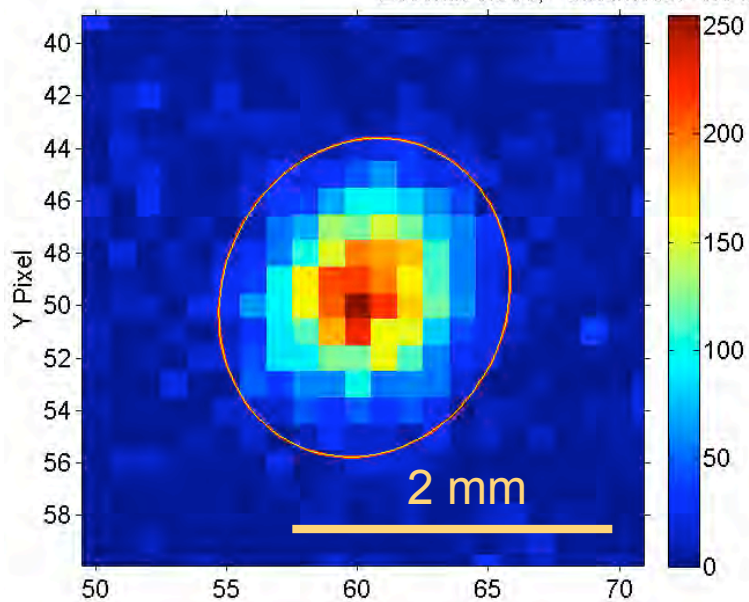


Detected Energy: 15.8 keVee, Recoil Energy: 33.2 keV, Track Length: 1.4 mm
 Track Length: 8.61 pixels, Track Area: 98 pixels, Angle: -31
 Eccent.: 0.396, Skewness: 0.053, Vector (x,y): [0.86, -0.511]

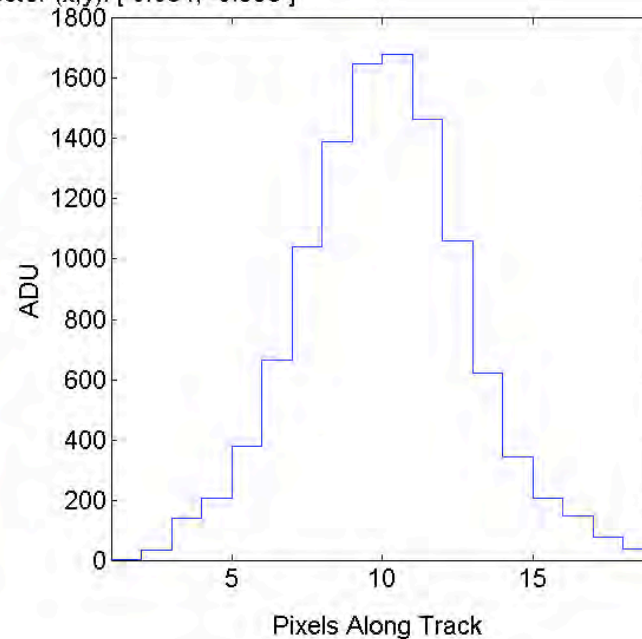
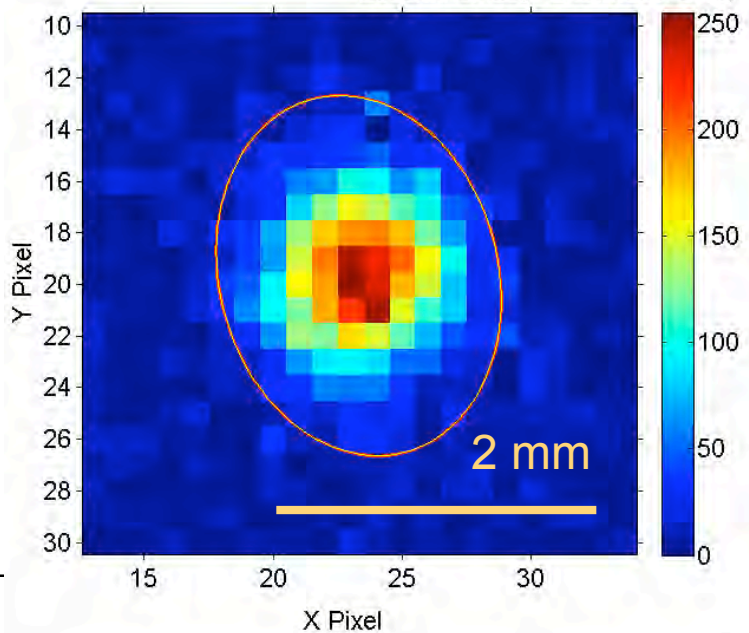


Nuclear Recoils

Detected Energy: 31.2 keVee, Recoil Energy: 57 keV, Track Length: 1.7 mm
 Track Length: 10.3933 pixels, Track Area: 162 pixels, Angle: 62
 Eccent.: 0.508, Skewness: -0.04, Vector (x,y): [-0.472, -0.882]

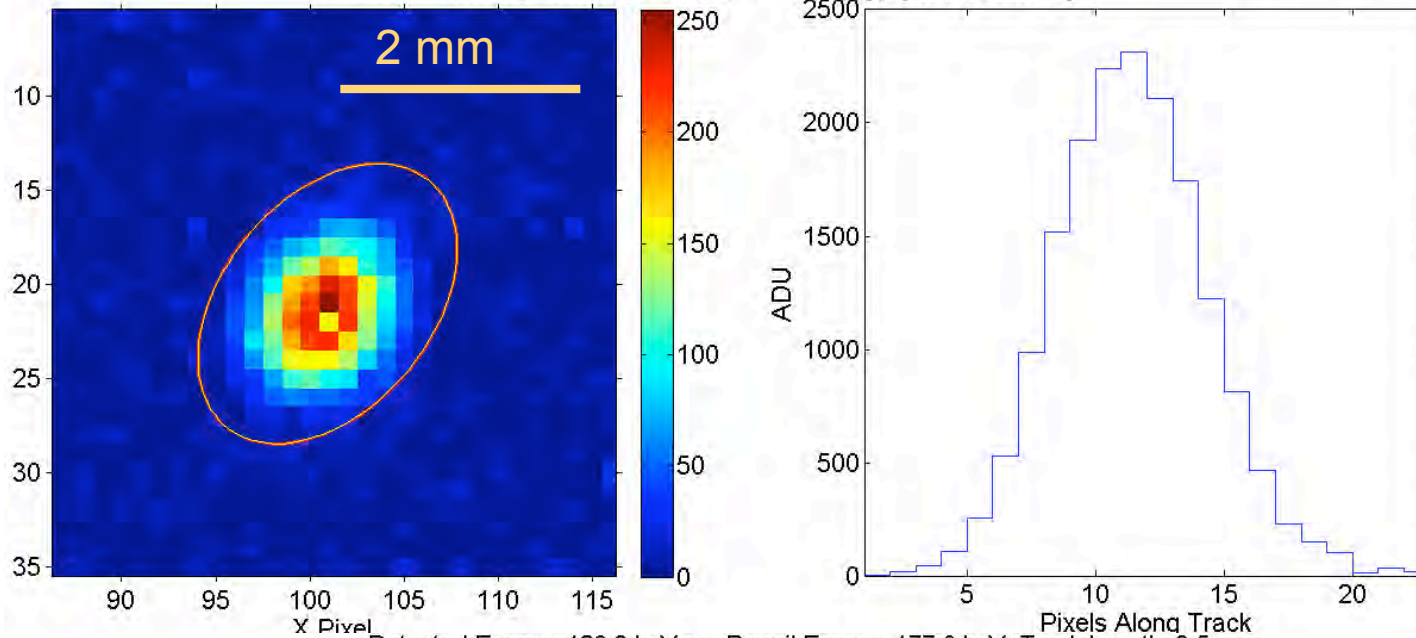


Detected Energy: 40.3 keVee, Recoil Energy: 70 keV, Track Length: 1.8 mm
 Track Length: 10.8559 pixels, Track Area: 180 pixels, Angle: -85
 Eccent.: 0.459, Skewness: 0.13, Vector (x,y): [0.084, -0.996]

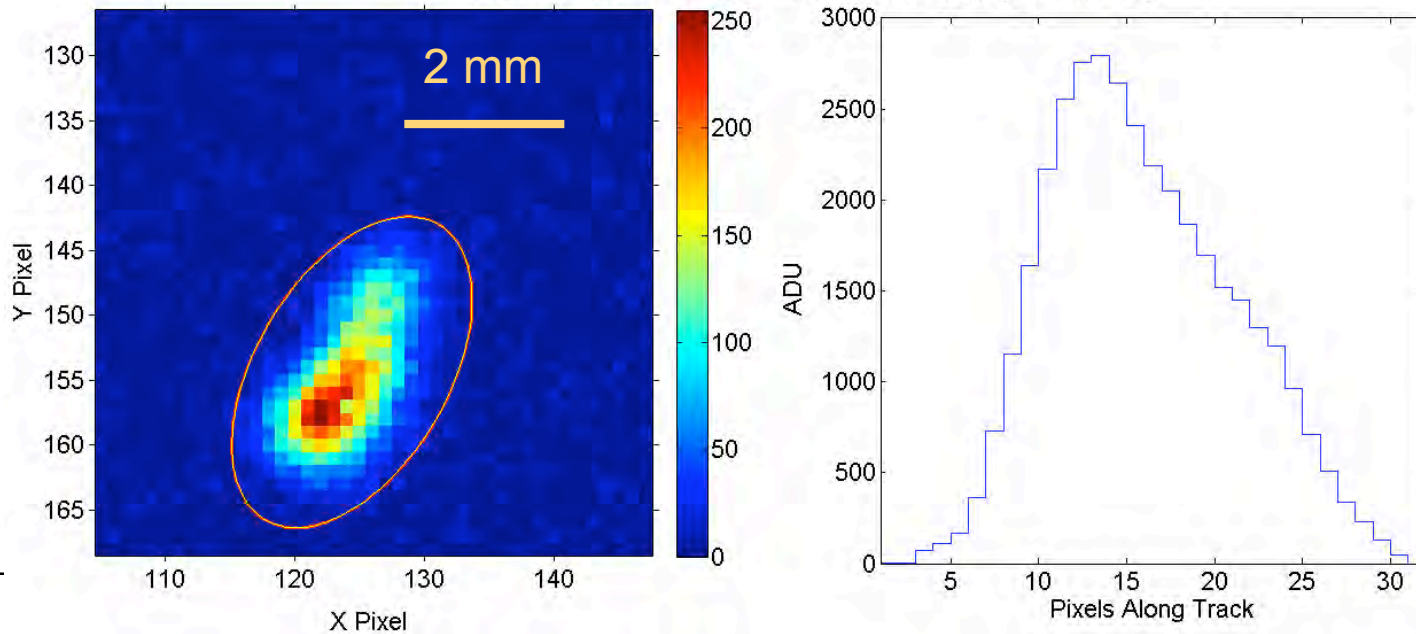


Nuclear Recoils

Detected Energy: 61.1 keVee, Recoil Energy: 97.6 keV, Track Length: 1.9 mm
 Track Length: 11.5817 pixels, Track Area: 217 pixels, Angle: 61
 Eccent.: 0.636, Skewness: 0.23, Vector (x,y): [0.486, 0.874]

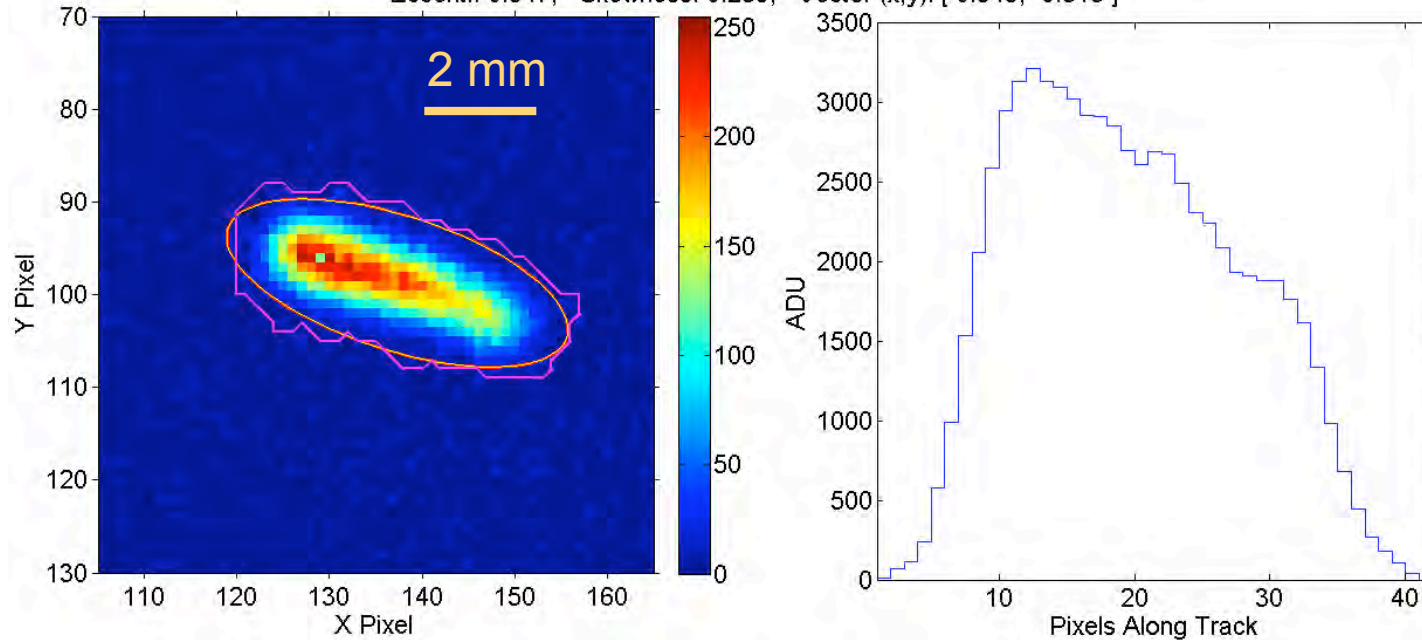


Detected Energy: 129.3 keVee, Recoil Energy: 177.8 keV, Track Length: 3.5 mm
 Track Length: 20.849 pixels, Track Area: 400 pixels, Angle: 62
 Eccent.: 0.86, Skewness: 0.341, Vector (x,y): [0.47, 0.883]

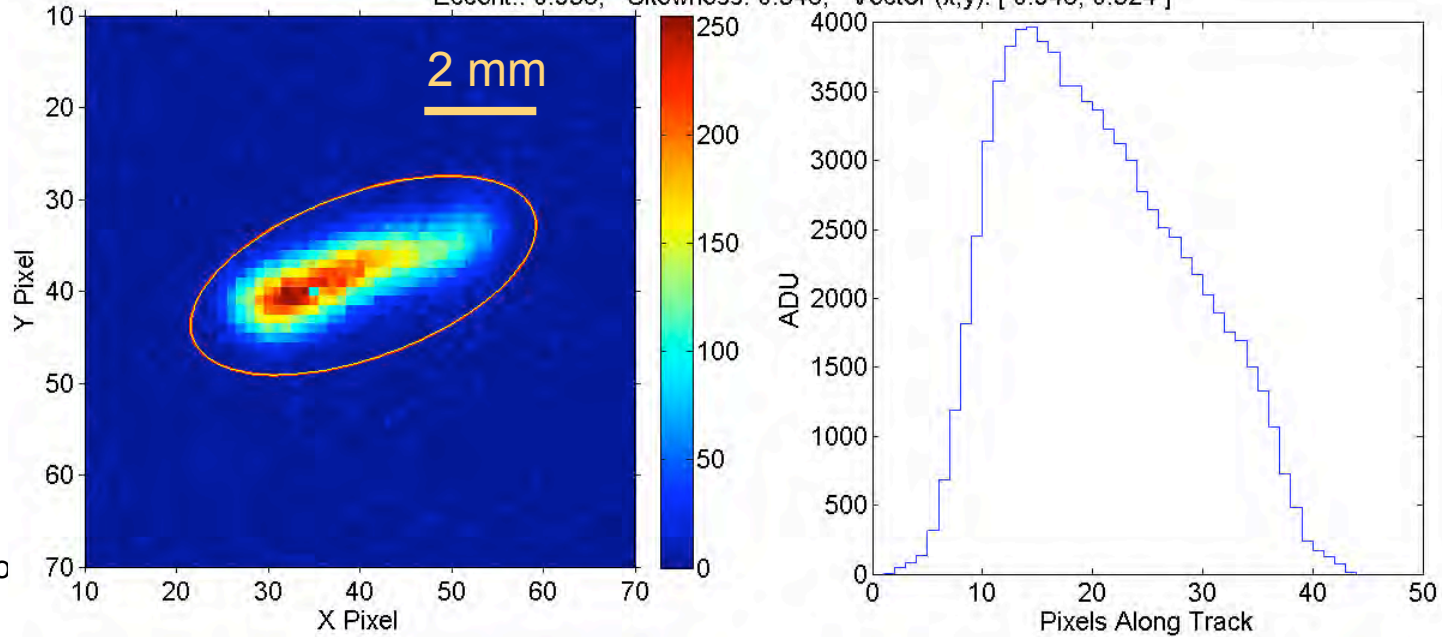


Nuclear Recoils

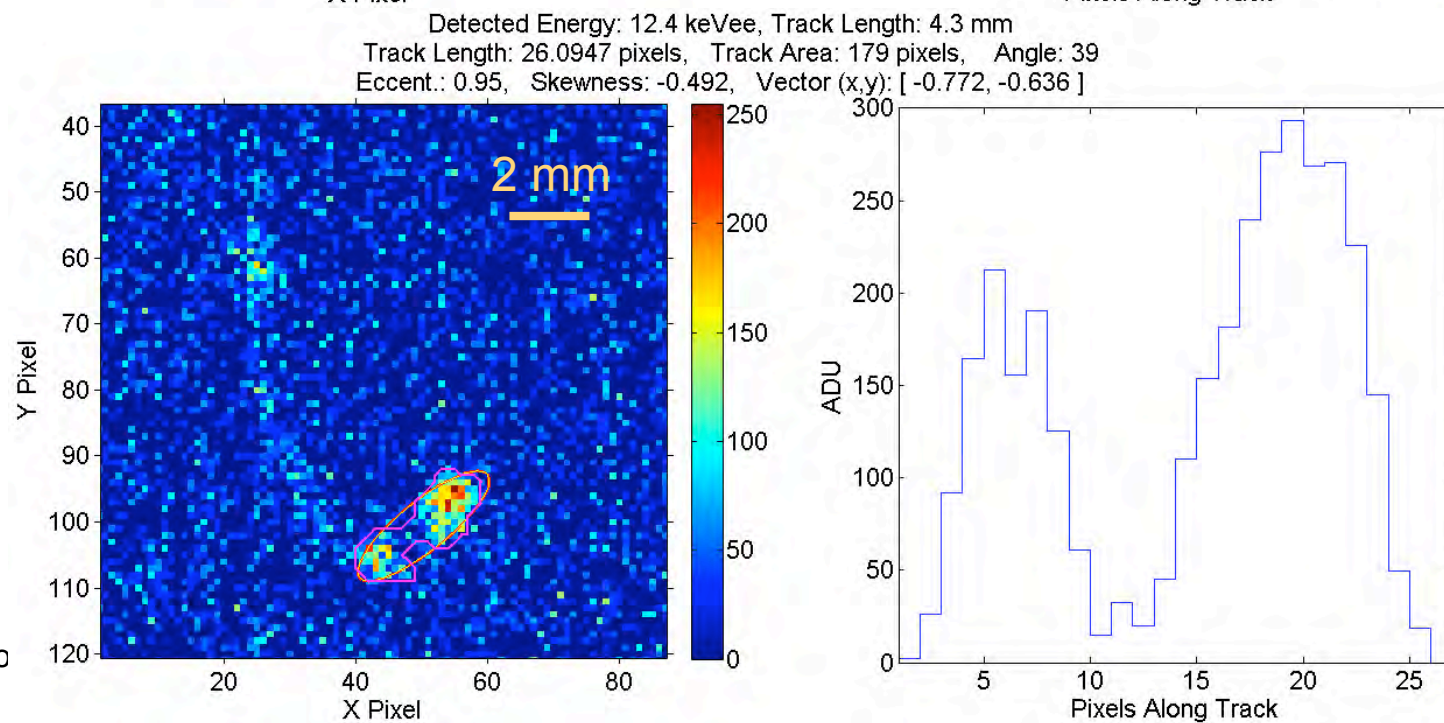
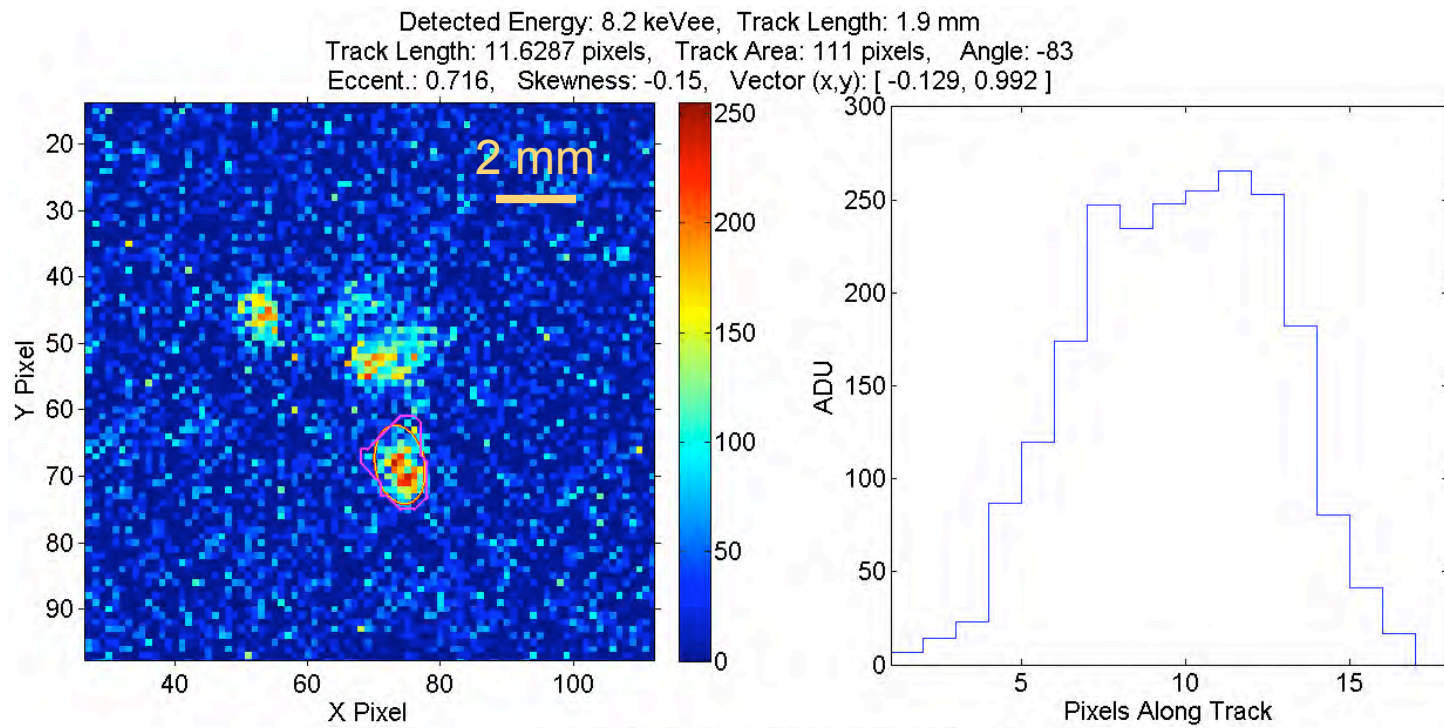
Detected Energy: 254.5 keVee, Recoil Energy: 305.6 keV, Track Length: 5.3 mm
 Track Length: 32.0609 pixels, Track Area: 560 pixels, Angle: -18
 Eccent.: 0.947, Skewness: 0.259, Vector (x,y): [0.949, -0.315]



Detected Energy: 302.4 keVee, Recoil Energy: 350.7 keV, Track Length: 5.4 mm
 Track Length: 32.5429 pixels, Track Area: 684 pixels, Angle: 19
 Eccent.: 0.938, Skewness: 0.346, Vector (x,y): [0.946, 0.324]

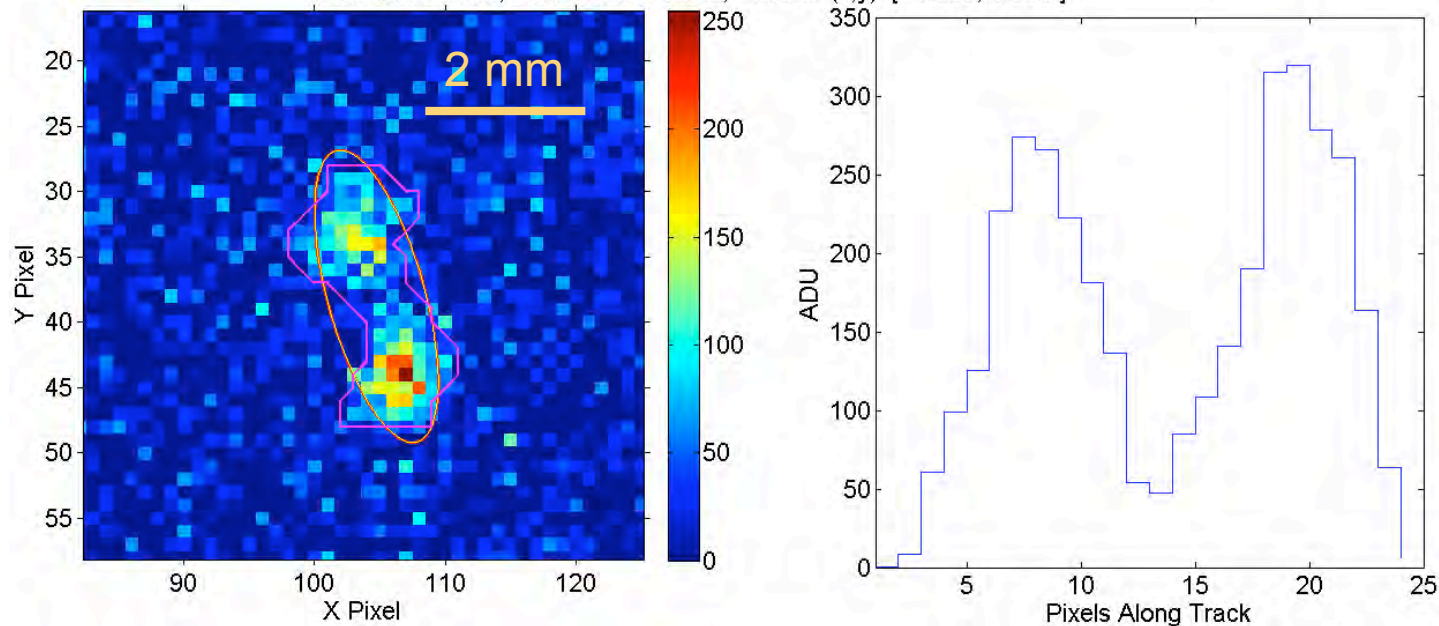


Electronic Recoils

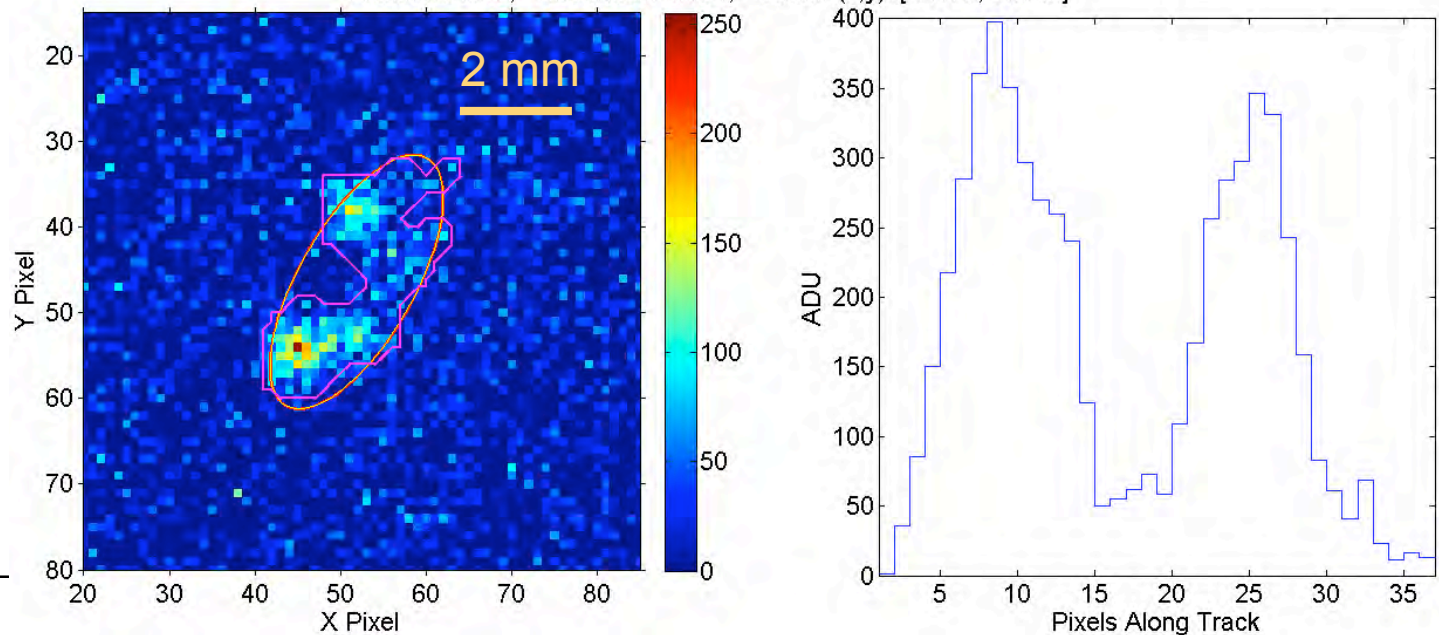


Electronic Recoils

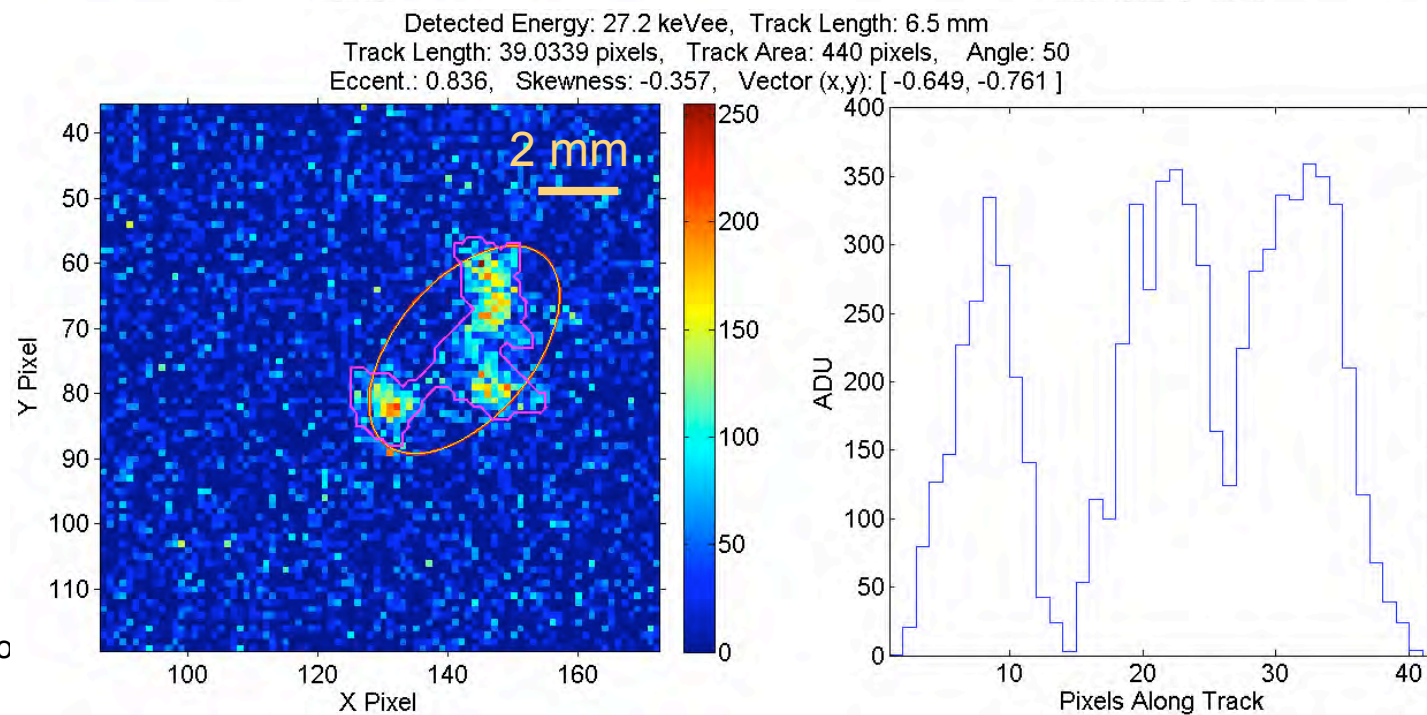
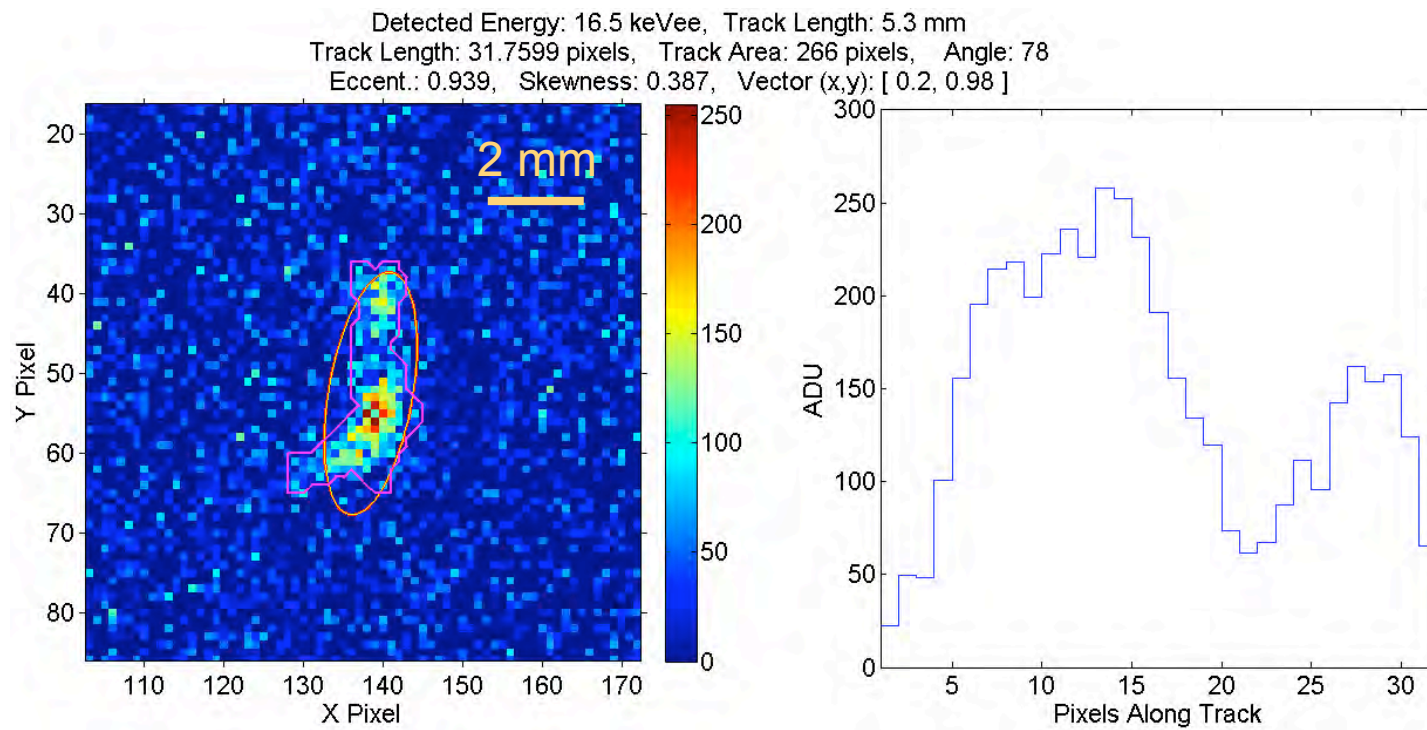
Detected Energy: 13.3 keVee, Track Length: 4 mm
Track Length: 23.8567 pixels, Track Area: 168 pixels, Angle: -74
Eccent.: 0.938, Skewness: -0.126, Vector (x,y): [-0.269, 0.963]



Detected Energy: 21.4 keVee, Track Length: 5.7 mm
Track Length: 34.2166 pixels, Track Area: 365 pixels, Angle: 61
Eccent.: 0.907, Skewness: 0.194, Vector (x,y): [0.479, 0.878]

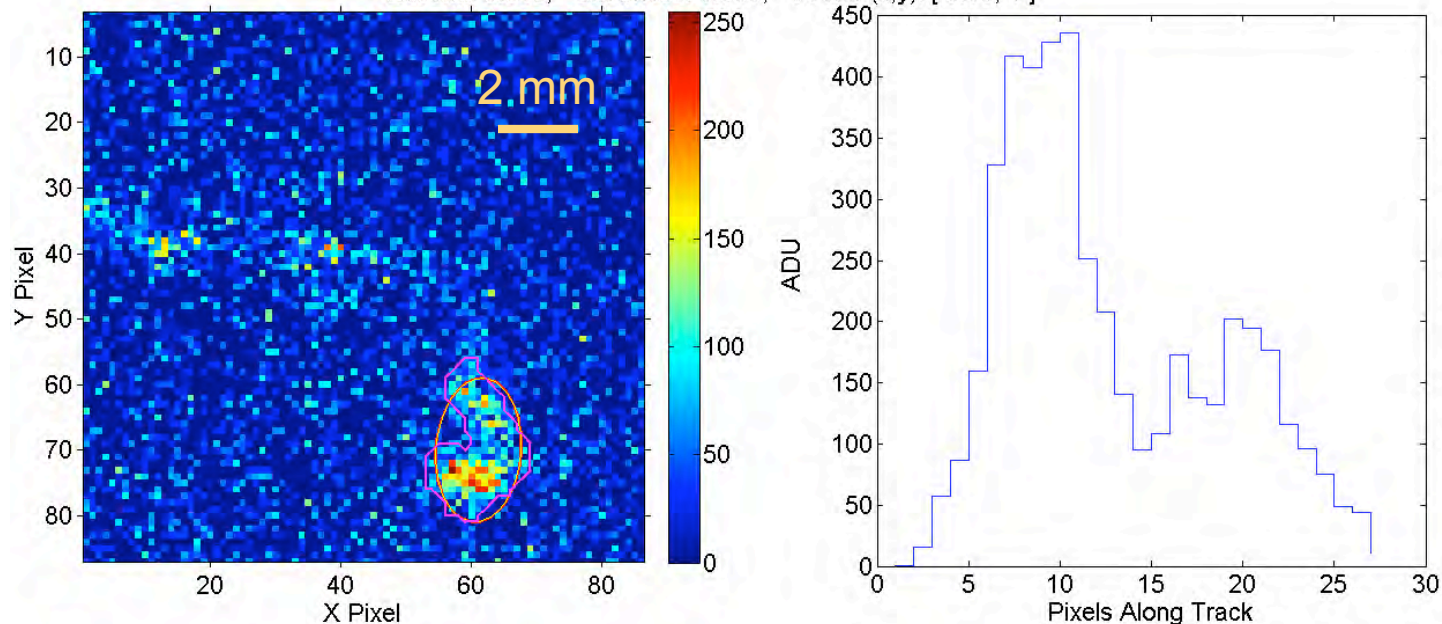


Electronic Recoils

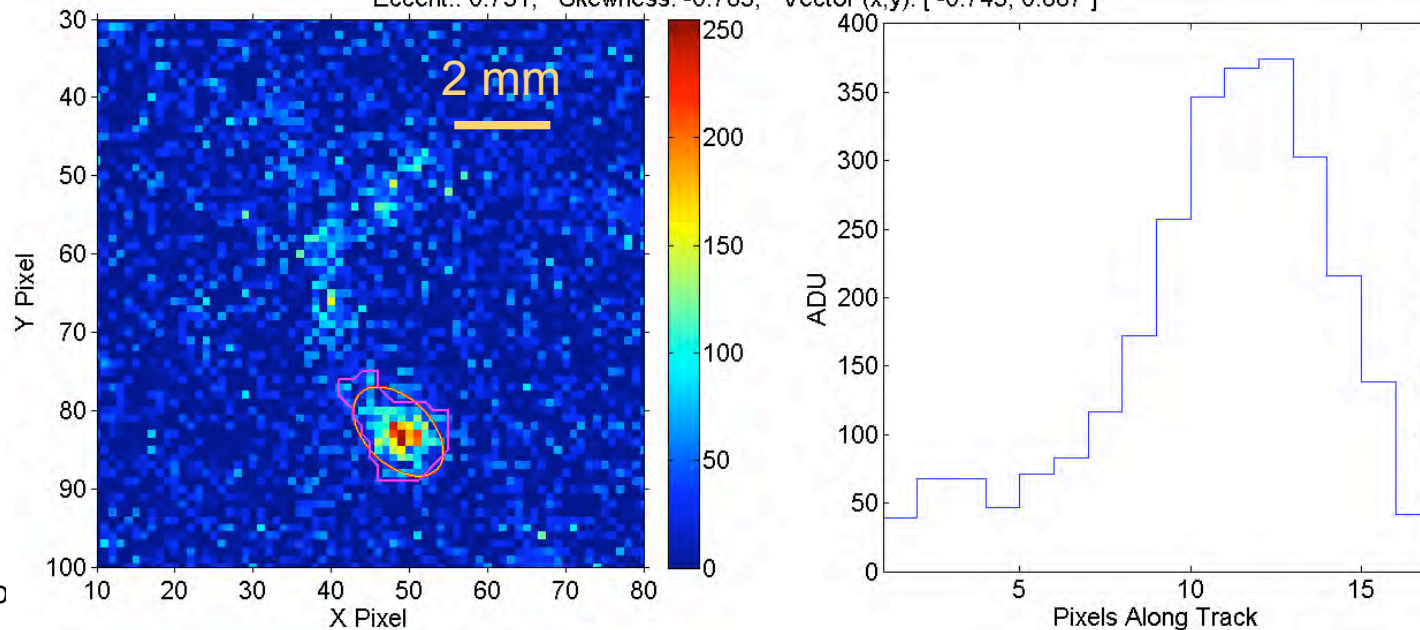


Electronic Recoils

Detected Energy: 16.5 keVee, Track Length: 3.9 mm
Track Length: 23.371 pixels, Track Area: 260 pixels, Angle: 88
Eccent.: 0.845, Skewness: 0.588, Vector (x,y): [0.03, 1]

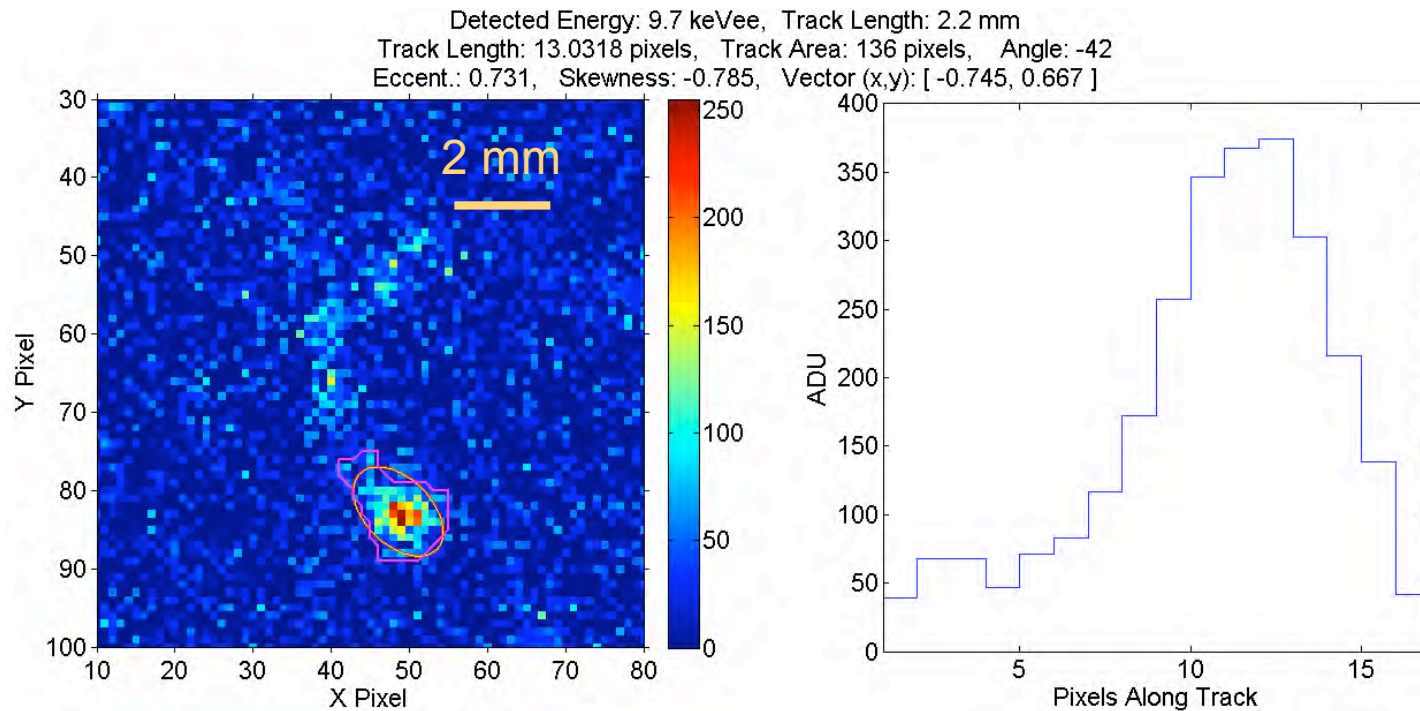


Detected Energy: 9.7 keVee, Track Length: 2.2 mm
Track Length: 13.0318 pixels, Track Area: 136 pixels, Angle: -42
Eccent.: 0.731, Skewness: -0.785, Vector (x,y): [-0.745, 0.667]



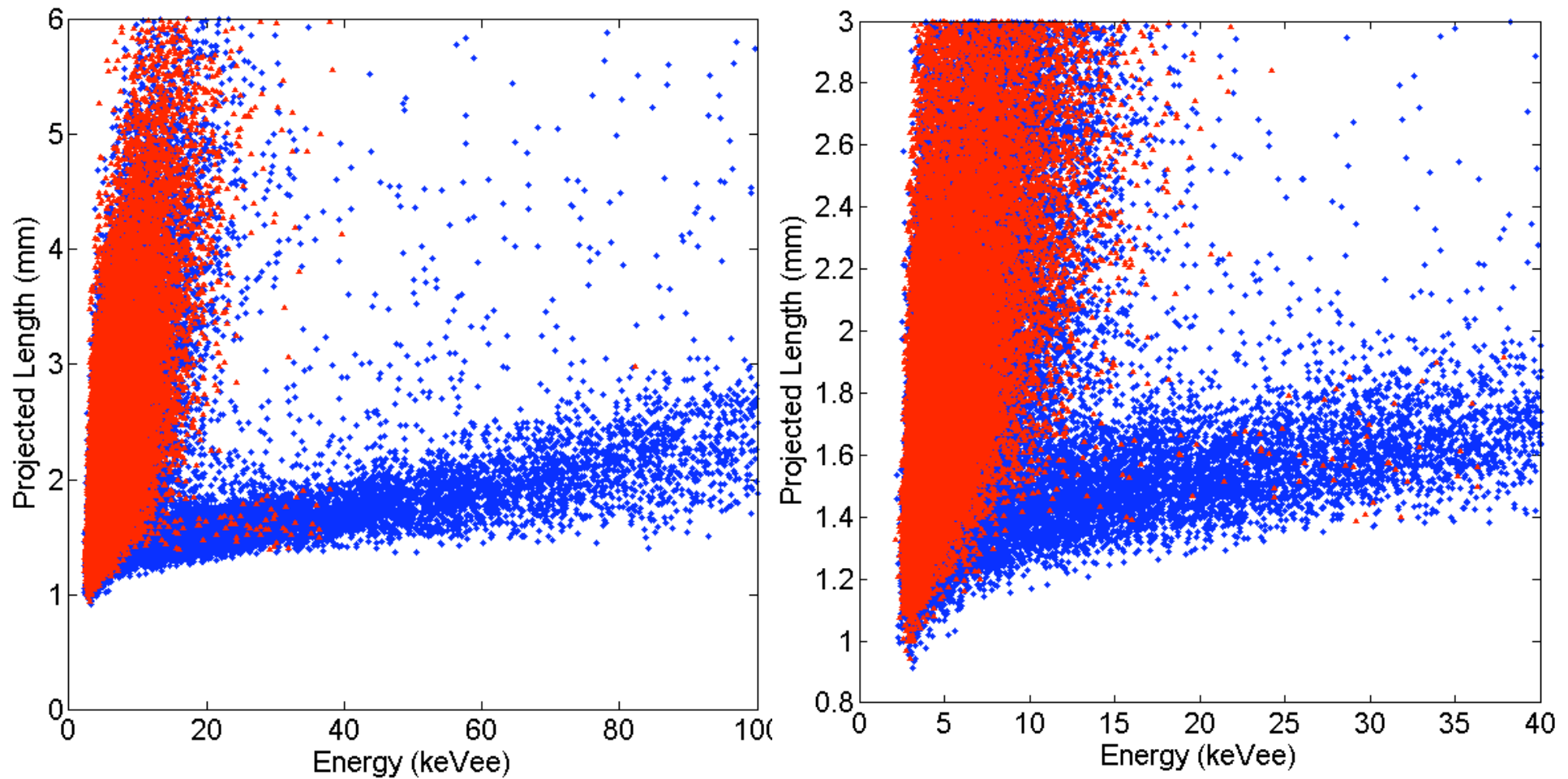
Good Discrimination requires high S/N

- Electronic recoils have **small** dE/dx with **large** fluctuations \rightarrow low S/N leads to confusion with nuclear recoils

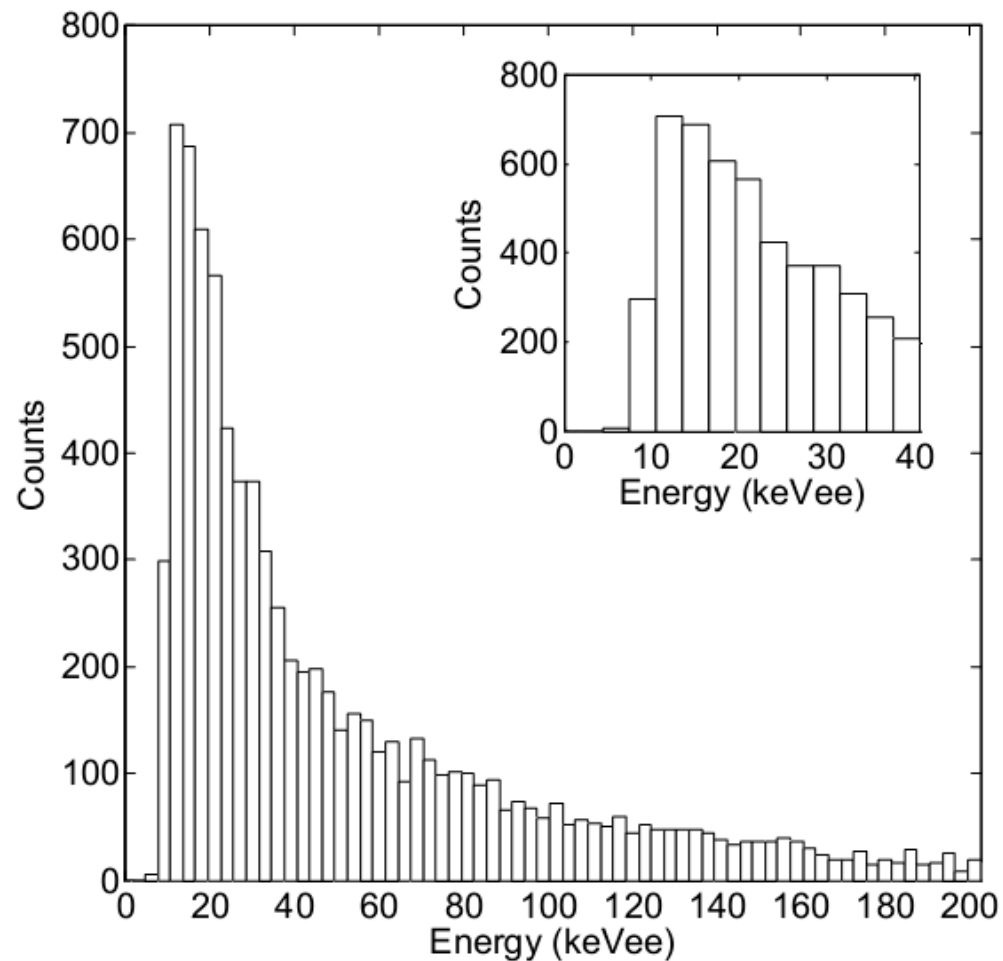


A ~10 keVee electron or a ~25 keVr F recoil??

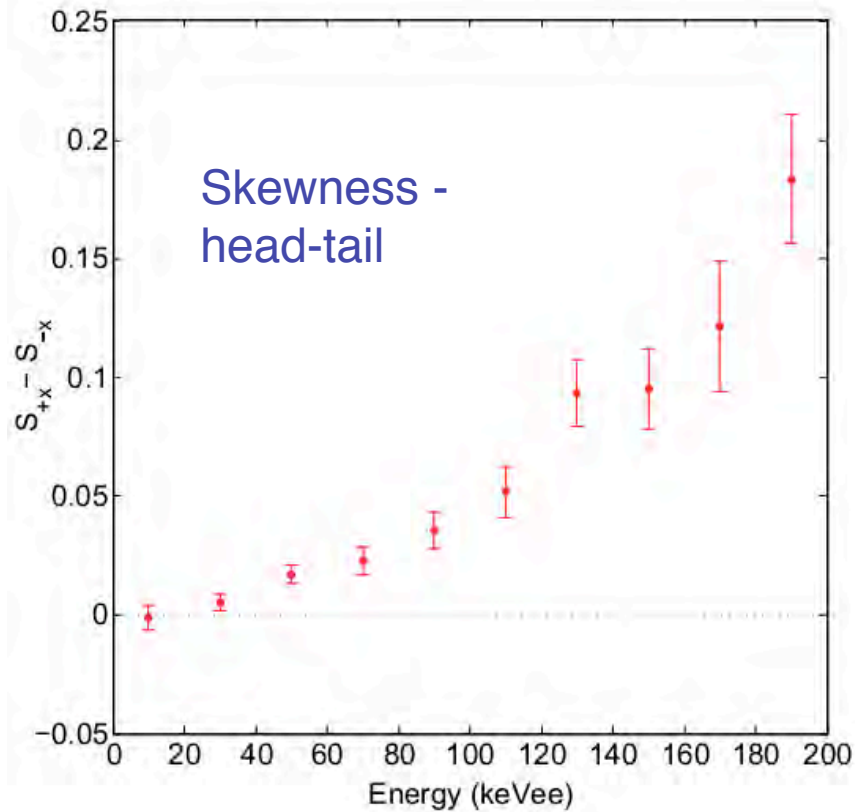
Overlay of neutron run data with gamma run data:
Excellent Discrimination down to ~10 keVee



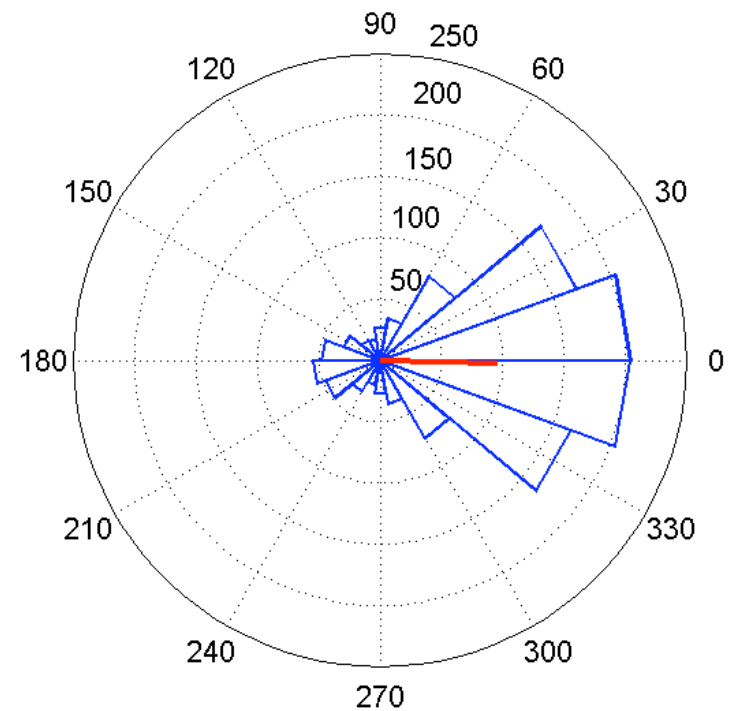
Energy spectrum of nuclear recoils post analysis cuts



Discrimination threshold in **100 Torr CF₄**: ~10 keVee (~**25 keVr**, Hitachi)



Excellent Directionality
(100 Torr): measure of
skewness leads to
head-tail



Implications for a directional low mass WIMP search

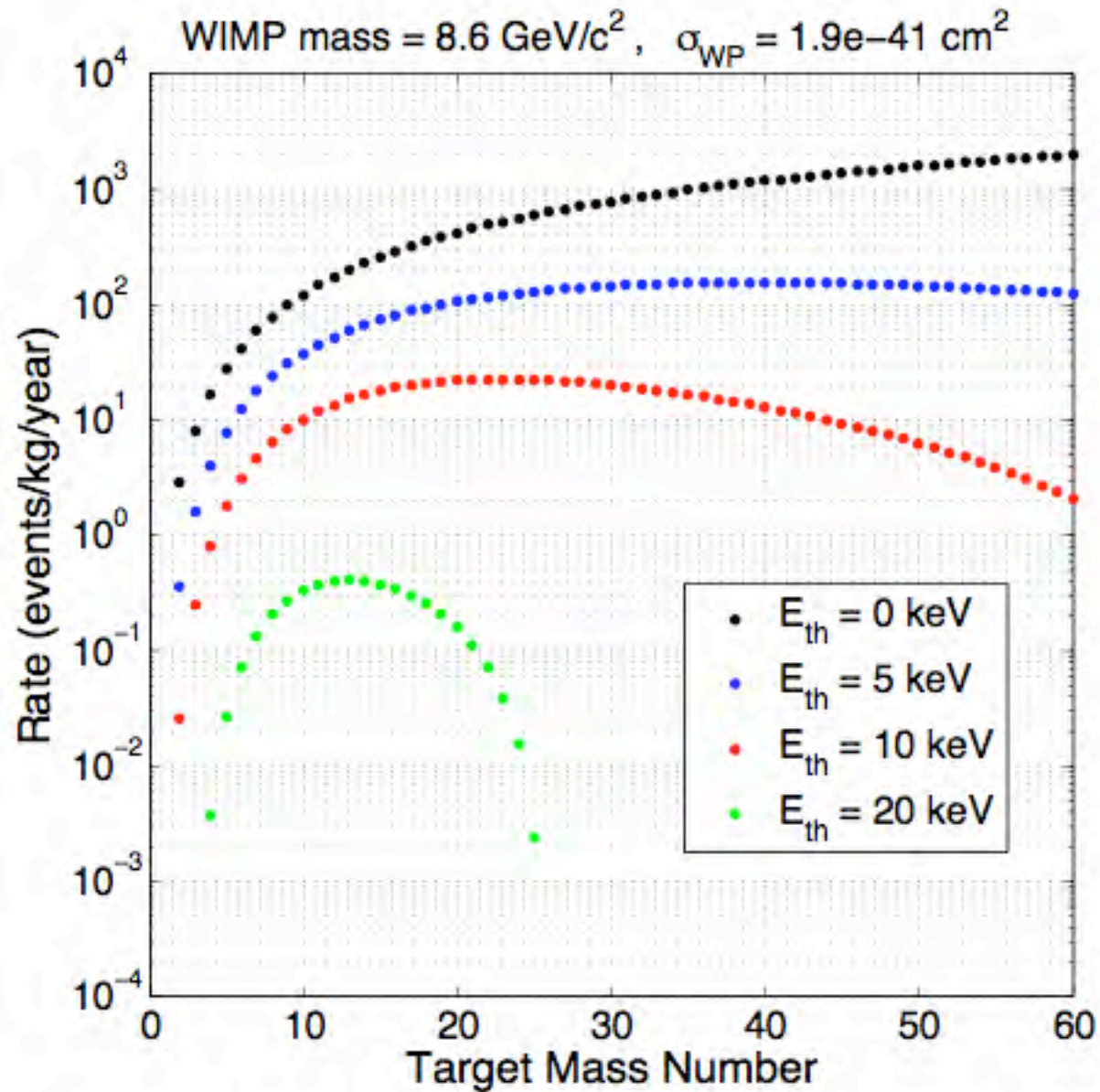
Can we use the results from this work to make a case study for **directional low mass WIMP searches**?

The experimental parameters critical to our results in 100 Torr CF₄ are all feasible:

1. high S/N
2. Low diffusion ($\sim 0.4\text{mm}$)
3. High spatial resolution

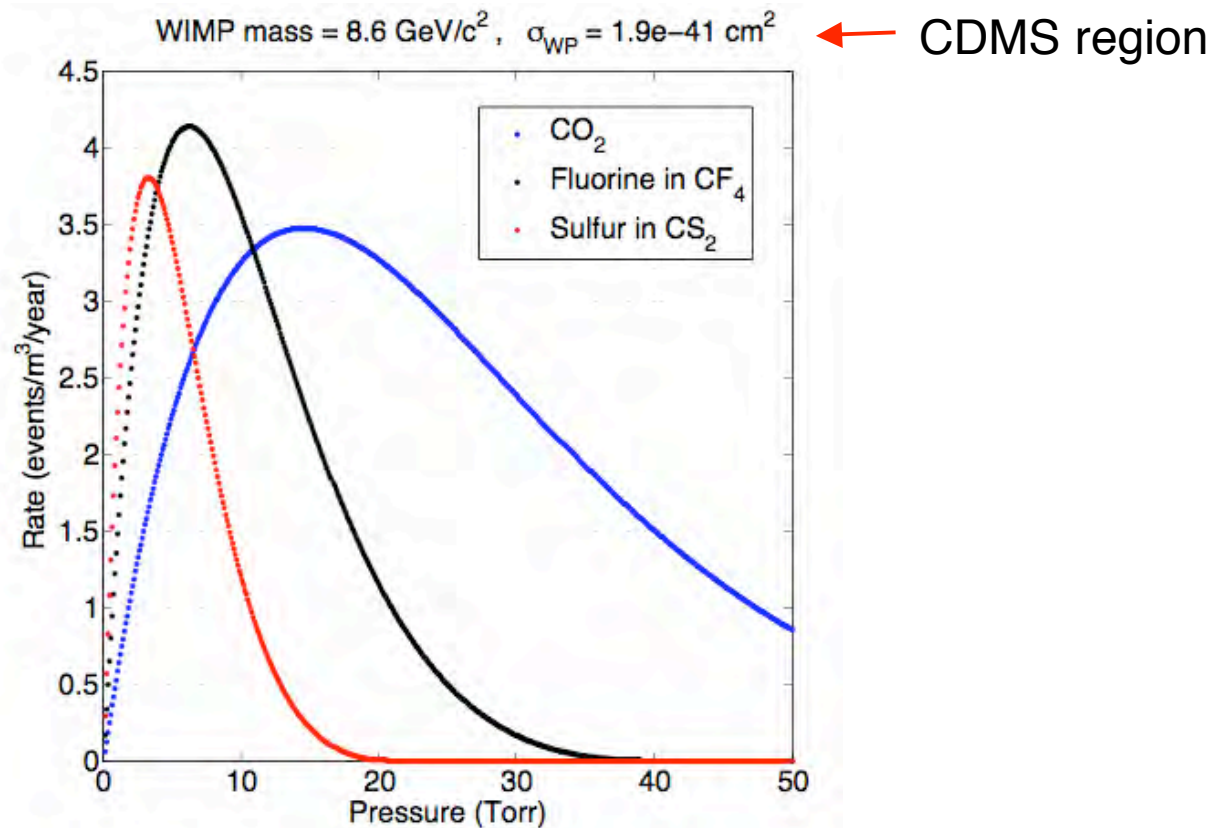
The first enabled excellent discrimination down to 10 keVee, the second enabled directionality at $\sim 55\text{ keVr}$. *In 100 Torr CF₄ the latter corresponds to F tracks with $R \sim 0.6\text{mm}$. We'll use this in the following.*

The CDMS Low Mass WIMP *

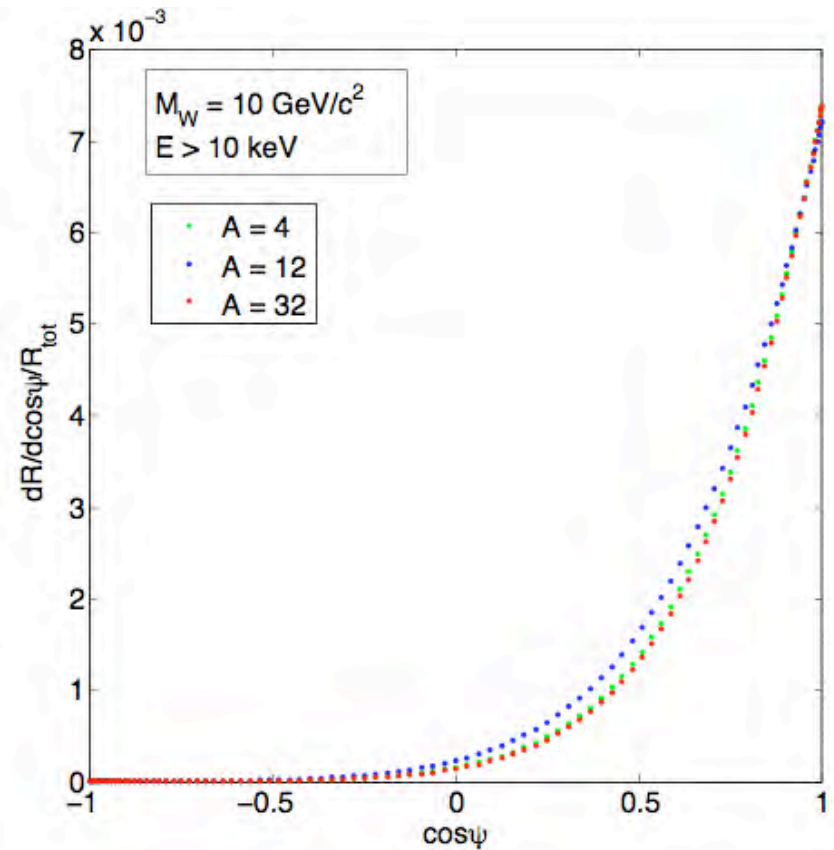
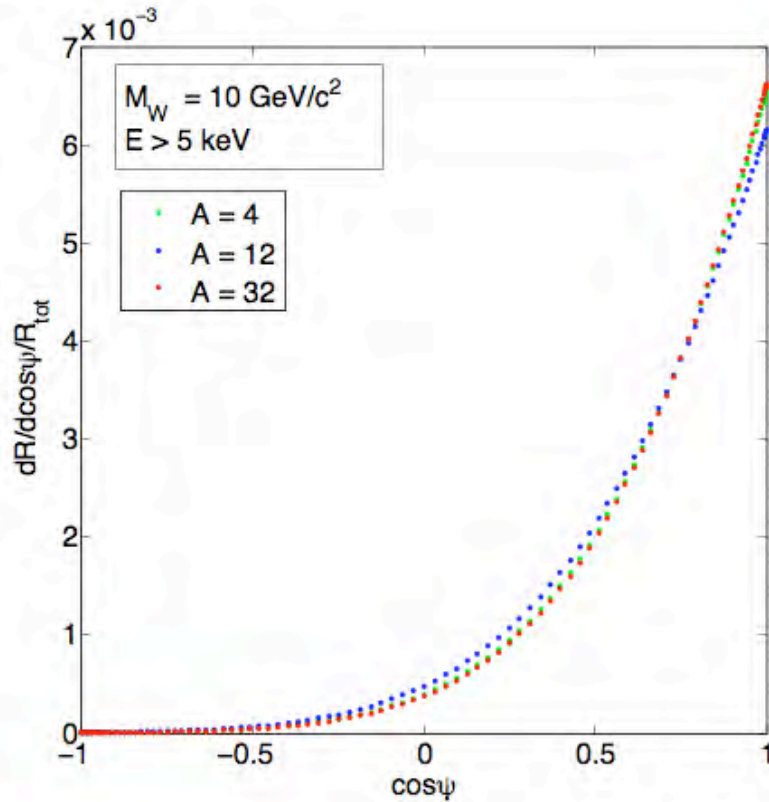


* We will assume a SI LMW

- Fix minimum resolved nuclear recoil range ($R \sim 0.6 \text{ mm}$) from our experimental data
- Define $E_{\text{threshold}}$ as that for which $R = 0.6 \text{ mm}$
- Maximize event rate ($> E_{\text{threshold}}$) in 1 m^3 as a function of target and pressure

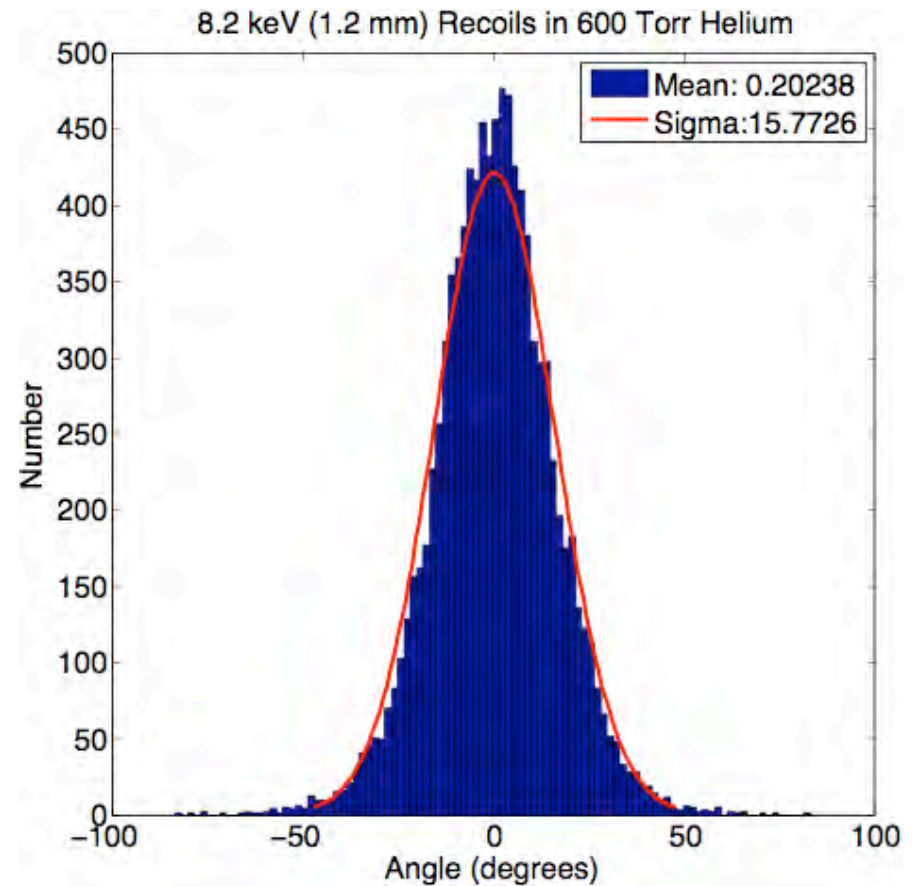
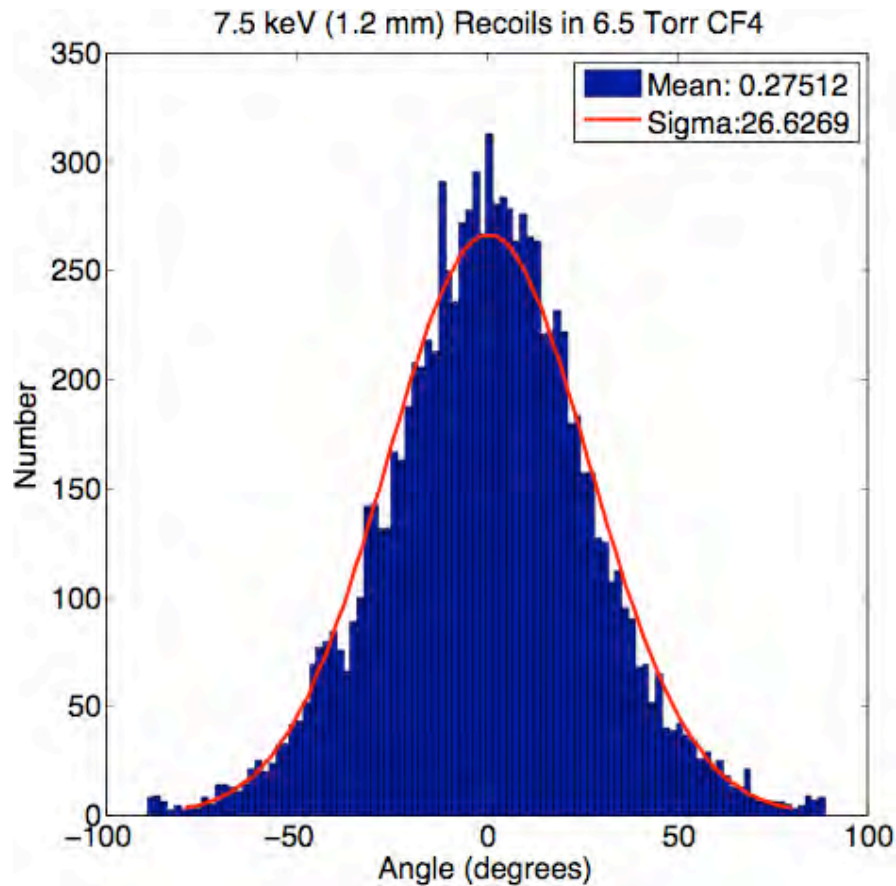


What about the angular spectra?



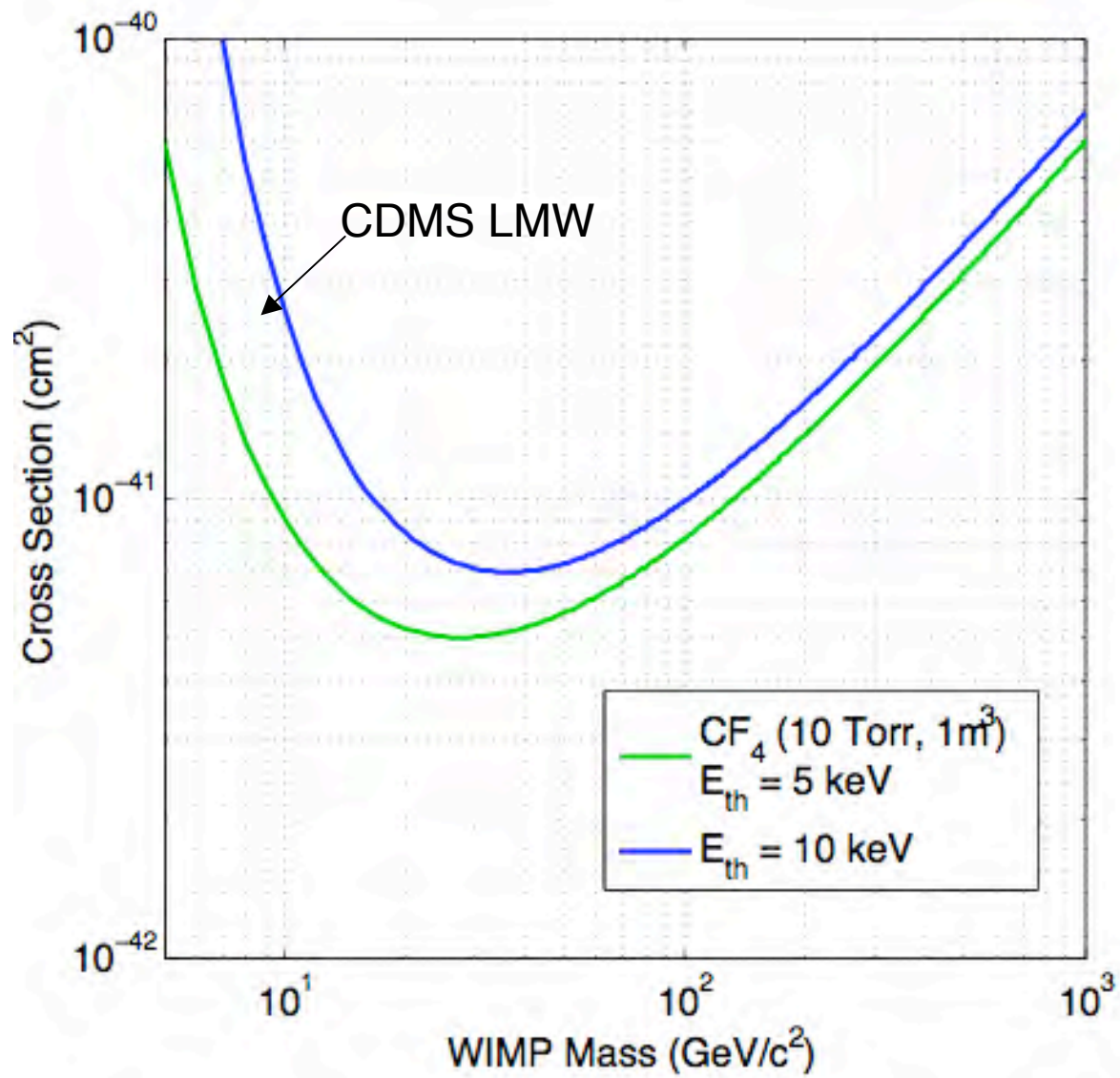
Agrees with Billard et al. PLB 691 (2010)

...and Straggling? *



* Here we used SRIM to generate 1.2 mm directional recoils of F and He, which were then diffused ($\sigma=0.4\text{mm}$) and run through our analysis. S/N was set high.

Limits in 1 yr for 1 m³



Conclusions

- RPR backgrounds eliminated: thin-film + fiducialization implemented in DRIFT-IIc and new limits forthcoming
- **DRIFT is now volume limited!**
- Engineering of a DRIFT-III prototype called DRIFT-IIe near completion and will be deployed soon
- Continue R&D to demonstrate directional sensitivity for low mass WIMP searches



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